EFFECTS OF
HIGH POWER LASERS,
NO. 7

November 1975 - June 1976

Sponsored by
Defense Advanced
Research Projects Agency

September 28, 1976

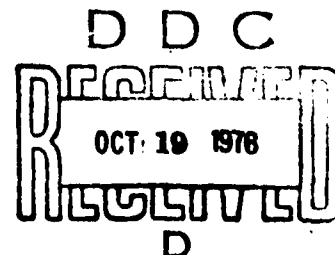DARPA Order No. 3097, Amendment 1

D D C

OCT 19 1976

Informatics inc.

Information Systems Company
6000 Executive Boulevard
Rockville, Maryland 20852
(301) 770-3000

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER	**2. GOVT ACCESSION NO.**	**3. RECIPIENT'S CATALOG NUMBER**
4. TITLE (and Subtitle) Effects of High Power Lasers, Number 7, November 1975 — June 1976.		**5. TYPE OF REPORT & PERIOD COVERED** Scientific. . . Interim **6. PERFORMING ORG. REPORT NUMBER**
7. AUTHOR(s) G. Hibben, J. Kourilo, M. Ness, B. Shresta		**8. CONTRACT OR GRANT NUMBER(s)** MDA-903-76C-0099, DARPA Order-3097
9. PERFORMING ORGANIZATION NAME AND ADDRESS Informatics Inc. 6000 Executive Boulevard Rockville, Maryland 20852		**10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS** DARPA Order No. 3097 Program Code No. P6L10, P6D10, P6E20, P6G10
11. CONTROLLING OFFICE NAME AND ADDRESS Defense Advance Research Projects Agency/TAO 1400 Wilson Boulevard Arlington, Virginia 22209		**12. REPORT DATE** September 27, 1976 **13. NUMBER OF PAGES** 123
14. MONITORING AGENCY NAME & ADDRESS(if different from Controlling Office) Defense Supply Service - Washington Room 1D245, Pentagon Washington, DC 20310	27 Sep '76	**15. SECURITY CLASS. (of this report)** UNCLASSIFIED **15a. DECLASSIFICATION DOWNGRADING SCHEDULE**

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

Scientific. . . Interim

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)
High power lasers
Beam-target interaction
Laser damage
Optical breakdown
Laser-plasma interaction

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)
This is the seventh compilation of abstracts of Soviet studies on high
power laser technology, covering material published from November
1975 through June 1976. Articles are grouped by laser interaction
with metals, dielectrics, semiconductors, miscellaneous targets, and
laser-plasma interaction.

A first-author index and an index of source abbreviations are appended.

DD FORM 1473 EDITION OF 1 NOV 65 IS OBSOLETE

INTRODUCTION

This is the seventh compilation of abstracts of Soviet studies on high power laser technology, covering material published from November 1975 through June 1976. Articles are grouped by laser interaction with metals, dielectrics, semiconductors, miscellaneous targets, and laser-plasma interaction.

A first-author index and an index of source abbreviations are appended.

TABLE OF CONTENTS

Summary

For metal targets, studies of dislocations in zinc are reported by Geptin and Larisa, in tests where effects of laser and other stress sources are compared. A paper by Samsonov also compares effects of electron beam, mechanical shock and laser irradiation on several transition metals. Devyatykh analyzes the aureole around target craters in Si, Cu and Zn, and Gazuko reports a study on damage to Zr, Ta and Ni carbides exposed to an Nd glass laser. Surface oxidation from c-w CO_2 laser irradiation of several refractories as well as low-melting metals is described by Arzuov. Studies of ejecta behavior and other damage phenomena are discussed by Alekseyev in tests on several metals using different lasing modes and power densities. Rykalin reports laser damage to molybdenum and steel plates as a function of ambient pressures up to 140 atm., using nitrogen; some dielectrics were also included in these tests. Pressure pulsations in laser targets were studied by Zhiryakov using a ruby laser on a mercury column,. and by Golubov using several metal foil targets. Two studies are reported by Kozlova on kinetics of flare formation on Al and Bi targets, in gaseous media including air, argon and helium. Other tests on foil destruction are described by Khokhlov on Al, Pb and Ta; by Tananykhin on Al, Ag and Cu films; and by Kovalev in an evaluation of gold coating of laser mirrors. Several studies concentrate on absorption and shielding effects of plasma generated on metal surfaces; these include brief abstracts by Anisimov and Gagarin, a report on shielding of Al, Pb and Zn targets by Lokhnygin, and evaluation of a shielding model given by Nguyen Tkho Vong. A damage model based on explosive phase transition is proposed by Martynyuk; Agashkov offers a simplified solution to heating of metal under free-running laser exposure. Two papers are included by Arifov which correlate electron and ion emission with laser parameters, using irradiated tungsten targets.

Several papers deal with various processing capabilities of lasers. Among these are the study by Dneprovskiy on laser deposition of rhenium films, by Rudnev on Al film deposition; by Kovalenko on laser hardening of metal valve seals, by Plyatsko on laser treatment of metals for improved corrosion resistance, and by

i

Alebastrova on shock wave and laser hardening of several metal powders.

Studies reported on laser effects in dielectrics are mostly concerned with the damage mechanism to laser optics, including both host materials and associated optical elements, since this is a major limiting factor to high power laser development. The correlation of material inhomogeneity with breakdown threshold is thus reported by Aleshin for several types of glass, while Morachevskiy describes techniques for observing laser damage formation in glass and plexiglass. Breakdown of KDP crystal by ultrashort Nd laser pulses is analyzed by Gridin, and Kikin investigates damage to ruby end faces owing to diffraction. The contribution of stimulated Brillouin scattering to breakdown in optical glass and quartz is reported by Vlasov.

The effects of inclusions are treated in an experimental study by Agranat on plexiglass, and in theoretical papers by Artem'yev and Tribel'skiy. Makshantsev discusses breakdown in transparent dielectrics theoretically, as a function of laser parameters, followed by an experiment with Kovalev to test the theory using PMMA exposed to a ruby laser. The theoretical effect of electron avalanching is treated by Babadzhan and also by Yepifanov. A theoretical study on laser-generated surface stresses in dielectrics is also presented by Lokhov. Buzhinskiy presents both theoretical and experimental findings relating damage threshold to laser pulse duration in glass. A study on reflectivity coefficients for a variety of glass and plastics is reported by Dlugunovich in damage tests with a CO_2 laser. Danileyko gives results of a study on nonlinear scattering effects in the vicinity of threshold for glass and sapphire.

In a paper on methods for improving optical strength, Yeron'ko describes a polishing and coating process which improves the laser performance of two types of glass; a similar experiment is briefly described by Ol'skaya for crystal specimens. Emission kinetics of molecules from laser-exposed glass is described by Zapechel'nyuk, and Kovalenko reports on experiments in laser cutting of diamonds.

Laser studies on semiconductors include articles on discrete damage effects as well as on less drastic thermal effects which can be used to enhance or alter a semiconductor's properties. Studies of damage formation in laser-exposed Si are reported by Obukhov and Kostyukova, and a theory of laser breakdown processes in semiconductors is proposed by Nguen Min Khiyen. Gomonova analyzes the recovery process in a photodiode exposed to excessive laser radiation.

Several studies are reported on laser annealing of existing defects in semiconductors, including one by Antonenko on laser anneal of Si, by Kachurin on anneal of Si and GaAs , and by Bolotov on anneal of ion-bombardment defects in GaAs . Laser doping of silicon by irradiation of films on the crystal surface is described by Blynskiy. Two papers by Tovstyuk discuss change in conductivity type by laser irradiation of CdTe and Pb-Sn-Te specimens.

A laser vaporization method is described by Agasiyev for depositing films of SbSI, Sb_2S_3 and InSe on various substrates. A brief abstract by Ivlev discusses generation of p-n junctions in GaAs by ruby and neodymium lasers. Fedorenko describes enhancement of photoconductivity in InSb under controlled laser exposure, and Dogadov reports on transmissivity changes induced by laser heating of GaAs . Both characteristic changes and damage threshold are studied by Myl'nikov in laser tests on several metalloorganic semiconductors.

Beam-target studies on materials outside the foregoing categories, together with more general theoretical treatment on concentrated heat flux effects, are grouped under a miscellaneous heading. Here Gorshkov reports on damage threshold in several alkali halide crystals using ruby and Nd glass laser exposure; and Geguzin discusses cavity formation in KCl crystal. Mukhamedgaliyeva investigates laser heating effects in $KAlSi_3O_8$; a study on laser vaporization of metallic aerosols is reported by Volkov. A simplified process for laser drilling of thin films is offered by Anisimova.

iii

Fedoseyev describes a laser heating method for determining thermal coefficients in solids, and a laser heater for crystal studies is proposed by Hanic.

In theoretical papers, a general study on flux heating of structural members is given by Samarin, although not specifically laser-related; Smirnov analyzes laser-induced stresses in thin circular plates. General considerations of material evaporation by laser are discussed by Lyubov, and Kozlov analyzes pulsations in the vaporization process. Kondrat'yev treats heating kinetics in an assumed planar target, while Yanushkevich analyzes shock wave effects in irradiated solids. Laser destruction of a liquid drop is discussed by Zemlyanov. A monograph by Mirkin gives a survey of damage effects and treatment techniques, indicating other potential applications for lasers in material processing. Two recent Soviet seminars on concentrated flux effects are reviewed by Uglov with respect to the laser-related papers.

The final section in the report includes all papers mainly concerned with laser interaction with plasma. While these and the foregoing beam-target categories are not mutually exclusive, it is felt that studies concentrating on laser plasma characteristics comprise a large enough field to warrant a separate category. A large portion of these papers is concerned, directly or indirectly, with laser fusion questions.

Basov, whose group at Lebedev Institute is the most active in laser CTR work, presents an optimistic review of the laser fusion situation, and concludes that the technology for it is at hand. Another paper by Basov discusses test results on heating and compression dynamics of several types of microballoon targets. The generation of a gas shell target for fusion use is proposed by Anisimov in a theoretical study, and two papers by Kaliski discuss implosion phenomena in laser fusion. A paper by Mak describes improved optics for aiming and focusing the laser beam on a small fusion-type target, and Zakharenkov discusses several types of optical data obtained from a laser plasma, using the nine-channel system developed by FIAN for CTR research.

iv

In other theoretical studies, Gamaliy analyzes the hydro-
dynamics of a laser plasma, and treats plasma diagnostics in a second
work. A study of plasma kinetics is given by Afanas'yev, and Lovetskiy
treats ion recombination in a laser plasma. Theoretical and experi-
mental findings on flare shielding are reported by Dymshits; shielding
effects are also treated by Stavrov. Experiments are reported by
Gerosimov on convection in a laser-heated gas, by Shkedov on various
flare parameters and by Dreyden on interferometry of a flare. Afrosimov
describes measurements of vacuum UV flux from a laser plasma; emission
from a xenon optical spark is reported by Kozlov. X-ray diagnostics
of a laser plasma are treated in reports by Kologrivov and Boyko, and
finally Kovalev describes tests on registering energy spectra of laser
plasma ions.

Conclusions

As in the previous reports on this topic, the Soviets continue
to indicate a substantial level of effort in the study of high power laser
effects on various materials. The reportage includes a large percentage
of theoretical studies along with the experimental results, as has also
been the case in the past. The recent coverage does not show any radical
changes or findings in the course of these studies, aside from the in-
creasing volume of material on laser fusion; one tends to come across
many of the same authors continuing work on their various aspects of
beam-target studies.

In attempting to evaluate Soviet research in the area of high
power laser effects vis-a-vis similar work in the U.S., one is struck by
the omission of coverage by the Soviets in several areas. This can be
seen, for example, by comparing the present material with the recent
ASTM Symposium report on laser damage in optics[1], which suggests

---

1) A. J. Glass and A. H. Guenther. Laser induced damage in optical
material: 7th ASTM Symposium. Applied Optics, June 1976, 1510.

a markedly broader and more intensive research program in this field. If some of the techniques reported here, such as diamond-turned metal mirrors, are being studied in the USSR, it is not apparent in their open literature to date.

Other examples of this sort can be cited; we see no parallel to the superimposed pulse studies reported for example by Fox[2] and Robin et al.[3] which show a dramatic increase in laser penetrability of a metal target. Some earlier Soviet work has appeared which correlates laser pulse shape with damage effect, but does not seem to have been followed up recently. However, in view of the pertinence of this type of study, it would seem prudent to assume that the Soviets are taking advantage of the cited findings, whether or not they are publicizing similar investigations. The usual caveat applies here, that the Russians release only sanitized versions of any research possibly relating to military use; one would hardly expect an article like Fox's to appear in a Soviet journal.

In the referenced ASTM Symposium report the authors give a warning concerning high-power optical materials research which is interesting to consider relative to the Soviet practice. The criticism is that much of the U.S. work is based on an empirical approach which seeks fixes after the fact, thus incurring penalties in cost and reliability, instead of building from a sound scientific base.

Since the Russians' strength in R&D is typically in the theoretical rather than experimental area, it may be that it is their theoretical output on high power laser effects which will prove the most valuable in the long run.

---

2) J. A. Fox. A method for improving continuous-wave laser penetration of metal targets. Applied Physics Letters, 15 June 1975, 682.

3) J. E. Robin and P. Nordin. Improved c-w laser penetration of solids using a superimposed pulsed laser. Ibid., 1 July 1976, 3.

1. Metal Targets

Khokhlov, N. P., Yu. V. Lisitsyn, V. N. Mineyev, and A. G. Ivanov. Laser destruction of metal foil. FiKhOM, no. 6, 1975, 3-7.

Test results are described on the destruction of Al, Pb, and Ta foils by Nd laser radiation. The laser (GOS-300M) was operated free-running, with energy $\sim$ 300 j in a power density range of 5×10^5 - 5×10^6 w/cm^2, $\lambda = 1.06 \mu$, and pulse width of one millisecond. Thickness of foil specimens was 0.05 - 0.25 mm; incident angles of radiation on the foil surface were i = 0, 30, 45, and 60°. Experiments were conducted under room conditions in air.

Destruction processes were recorded by an ultra-high-speed camera providing 62,500 frames/sec. Measurements of energy and recording of pulse shape (of incident radiation and of radiation passing through the destruction region) were made with calorimeters and photo-detectors.
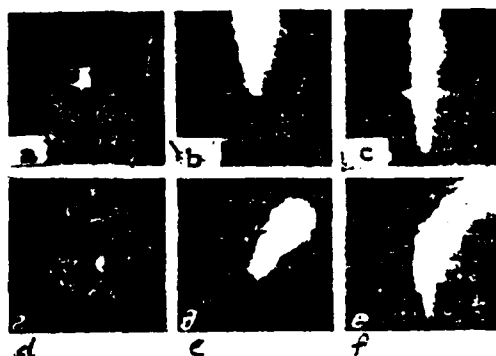

Fig. 1. Pictures of laser interaction with tantalum foils of 0.1 mm thickness.

a, b, c - i = 0°, Q = 2.7 kj/cm^2; d, e, f - i = 45°; Q = 0.65 kj/cm^2. Time of forming flare on the irradiated surface, in μsec: a - 32; b - 288; c - 640; d - 32; e - 288; f - 640. One square = 10 x 10 mm.

Fig. 1 shows typical pictures of the laser interaction process with Ta foil. Propagation of the flare at i = 0 is perpendicular to the surface, while for i ≠ 0, it deviates towards the laser beam axis increasingly with increase in i.

Relationships are obtained for the rate of material scattering, target destruction time, quantity of ejecta and parameters of radiation passing through the destruction products, as functions of power density and incident radiation angle on the specimen surface. Results are presented graphically. The average density and absorption coefficient of the destruction products of the tested foils are estimated. The results are discussed and the relationship of target destruction parameters to the thermophysical properties of the test metals are explained. It is pointed out that destruction characteristics of Pb, Ta, and Al vary systematically with changes in heat content, thermal conductivity, heat of vaporization and heat of fusion. The time for target destruction increases, while the quantity of material ejecta decreases, with increase in the above thermo-physical properties.

Martynyuk, M. M. <u>Explosive mechanism of metal destruction by powerful electromagnetic radiation flux.</u> ZhTF, no. 4, 1976, 741-746.

The process of metal destruction by powerful e-m flux is analyzed, based on the thermodynamic and kinetic transition of a liquid metal into vapor under rapid heating. The possible existence of a metastable liquid-metallic phase, and its explosive transition to a stable two-phase state (phase explosion of metastable liquid), is analyzed. It is shown that at radiation flux densities which cause metal heating up to a spinodal temperature point T_s in an interval $t_s = 10^{-7}-10^{-5}$ sec, evaporation from a liquid metal surface is negligible and the main mechanism of metal destruction is the explosion of the metastable liquid-metallic phase, which begins to develop in the vicinity of T_s. Based on experimental data

from electric wire explosion at $t_s = 10^{-6} - 10^{-5}$ sec, excess enthalpy and the fraction of the vapor phase resulting during phase explosion of Cu, Ag, Au, Zn, Cd, Al, Pb, Zr, Nb, Mo, W, Pt and R are calculated and the results tabulated. Characteristics are discussed of phase explosions at flux densities corresponding to $t_s \leq 10^{-8}$ sec. In this interval the thickness of the ejected layer during a single phase explosion is smaller by one order than for $t_s = 10^{-6}$ sec. Furthermore, at $t_s \leq 10^{-8}$ sec, the value of t_s may be smaller than the characteristic time for a steady-state nucleation process, such that during phase explosion the stability of the homogeneous nucleation process may be disturbed, leading to a relatively large time lag in material ejection.

Nguyen Tkho Vyong. Phenomenological mechanism of destruction of a metal under the action of laser radiation. ZhPS, v. 23, no. 4, 1975, 586-589.

Based on a thermal damage model, laser destruction of metals at flux density of $10^9 - 10^{10}$ w/cm^2 has been studied in numerous published works. Results of these works show significant disagreement with experimental observations. The author asserts that these discrepancies between theoretical and experimental results are due to the fact that the model of thermal destruction mechanism does not take into account the effect of radiation shielding by vapors of evaporating particles, or the reflection of radiation from a specimen surface.

The present work suggests a new physical model, which eliminates these defects of the thermal mechanism and gives more realistic results. Equations are developed for the destruction processes of a substance, where destruction is caused by an effective flux which is the incident flux less absorbed and reflected flux, $q_{eff} = q_{in} - q_{ab} - q_{re}$. Expressions are derived for absorption coefficient k and depth of hole (i.e. boundary between two phases). Table 1 shows calculations made for depths of hole formation by laser pulses of 44 nsec duration and flux density $q = 10^9$ w/cm^2.

Table 1. Depth of hole formation by laser radiation, in microns

Metals	Depth of hole calculated in (1)[*]	Depth of hole calculated in the present work	Experimental results
Steel	1.8	1.4	1.2
Nickel	2.4	˙1.83	1.2
Copper	3.0	2.34	2.2

(1)[*] - A. M. Bonch-Bruyevich, et al. ZhPS, 1, 45, 1964.

It is seen that the obtained results in the present work are closer to agreement with experimental observations. A small discrepancy that still remains is ascribed to neglecting the effect of scattering from the products of optical erosion.

Geptin, A. P., R. R. Larina, and L. I. Mirkin.
Peculiarities in dislocation structures of zinc,
resulting from laser irradiation. IVUZ Fiz, no.
4, 1976, 26-30.

Dislocation effects were studied in zinc, exposed to a laser
beam as well as other concentrated mechanical and thermal stresses.
The zinc single crystals used were highly pure and were grown by zone
refining; they were split along the base plane at liquid nitrogen temperatures.
Irradiation was done with a GOS-30M glass laser, operating in a free-running
regime, at various temperatures and pulse energy densities with pulse
durations of 10^{-3}, 10^{-8} and 10^{-11} sec. Concentrated mechanical deformation
was obtained by a pyramidal indentor, and concentrated thermal stress by
a hot needle technique.

Microphotographs of dislocation structures are included, and
show that concentrated laser, mechanical and thermal treatments on crystal
specimens result in different types of dislocation structures. This indicates
that different mechanisms are possible for plastic deformations with the
cited treatments (Fig. 1). The processes leading to dislocation structures
from laser exposure are discussed in detail; this includes an analysis of
the spatial distribution of dislocations and their behavior at different temperatures.
Conclusions are:

1. The region of plastic deformation in the vicinity of beam
impact has a spherical form, which is markedly different from the observed
concentrated mechanical and thermal deformations.

2. As a result of deformation of crystal surface by laser
beam, bending of atomic planes is noted near the area of beam interaction.

3. Measurements of the distribution of dislocation density and
dimensions of the deformation region as a function of crater depth show that
a decrease in pulse duration leads to sharp increase in dimensions of the

deformation region. This is ascribed to the fact that the physical mechanism of deformation changes from a nonequilibrium thermal effect to a shock wave effect.
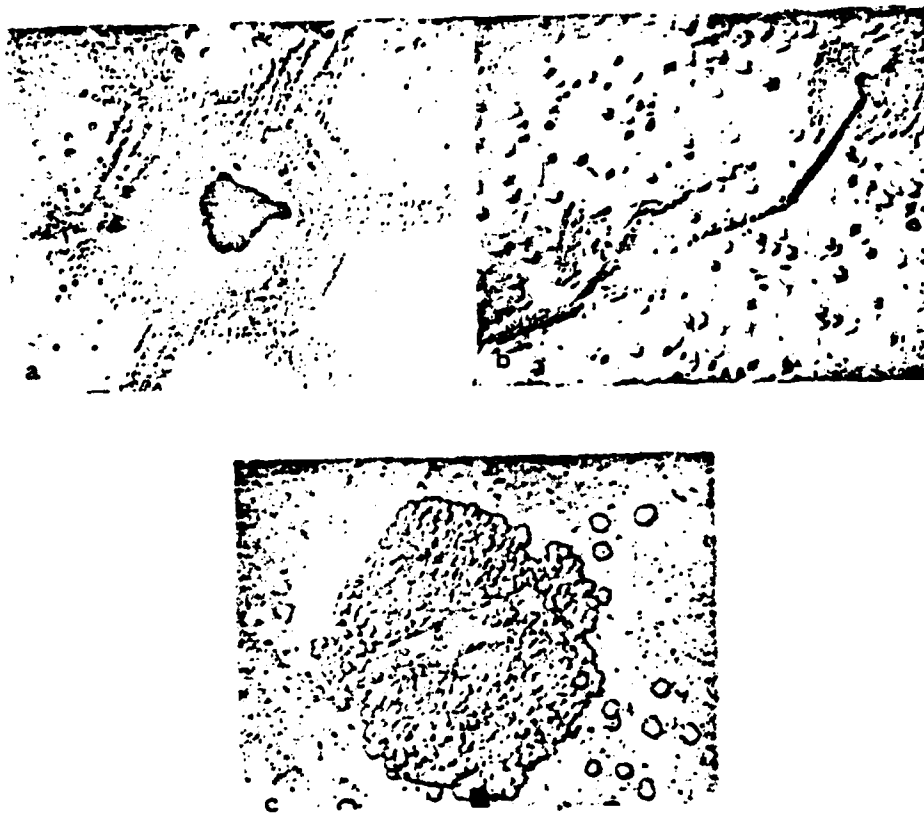

Fig. 1. Dislocation structure of zinc in the (0001) plane in the vicinity of:

a - laser crater, 10^{-3} sec pulse, x70;
b - mechanical indentation, x70;
c - application point of hot needle, x106.

Gazuko, I. V., I. M. Gryaznov, and L. I.
Mirkin. <u>Destruction and thermal dissociation</u>
<u>of carbides of transition metals under the</u>
<u>action of a laser beam.</u> FiKhOM, no. 6, 1975,
8-12.

Experiments are reported on baked monocarbides of zirconium,
niobium and tantalum exposed to high-power laser radiation. The laser used
in the experiment was the GOS-30M pulsed Nd laser with pulse width of
10^{-3} sec and energy up to 30 j. Effects were studied both by metallographic
and x-ray structural analysis. Microhardness of the specimens was measured
at loads up to 200 g.

The main effect of pulsed laser radiation on the cited materials
was found to be mechanical destruction without any changes in their chemical
structure. However, structural changes observed in thin surface layers and
in ejecta showed a significant change in their phase composition and lattice
constant. Laser irradiation of thin layers led to burning of carbon in air,
forming carbides of identical structure with changes in lattice constant,
carbides with less carbon content, basic metals and layers of carbide solutions
with oriented structures.

Analysis of ejecta showed the following changes in lattice constant:
Lattice constant of ZrC before irradiation was 4.696±001 Å, and after
irradiation and ejection it was 4.684± 001 Å, i. e. decreased by 0.01 Å.
Similarly, lattice constants of NbC and TaC before irradiation were 4.468±
0.001 and 4.456±0.001 Å and after irradiation - 4.428±0.001 Å and 4.449±
0.001 Å, respectively. These effects were found to decrease very sharply
when vacuum pressure during irradiation was varied even by an insignificant
amount $(10^{-1} - 10^{-2}$ torr.). Fig. 1 shows examples of irradiated tantalum
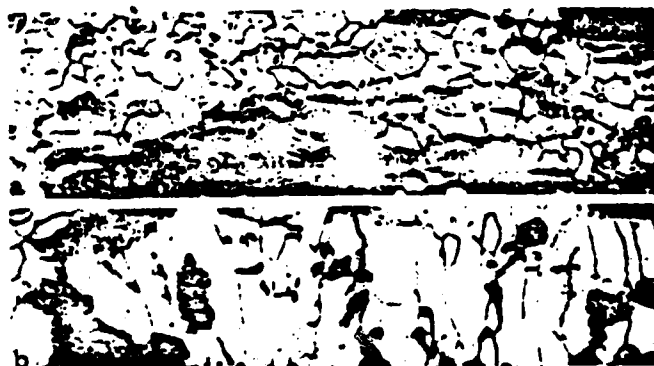carbide.

Fig. 1. Structure of solidified melt on
the surface of TaC after irradiation.

a - normal to beam; b - along beam path.
X450.

Discussions are outlined of the obtained results and physical
processes leading to the observed effects are explained.

Zhiryakov, B. M., N. I. Popov, A. A.
Samokhin, and A. K. Fannibo. Pulsed regime of
developed vaporization of a metal under the action
of laser radiation. ZhTF P, v. 1, no. 15, 1975,
731-734.

A pulsed regime of mercury evaporation exposed to smooth
laser pulses is experimentally observed. A ruby laser operating in a
quasistationary regime with a shutter forming single square pulses of 50 to
500 μsec, was focused on the surface of liquid mercury, placed in a vertical
glass capillary of 1.6 mm diameter and 18 mm long. Power density I at
the 1.5 mm diameter focal spot was up to 10^6 w/cm^2. A piezoceramic pickup
was located at the bottom of the capillary, in order to register changes in
pressure of the mercury column. The vaporization process was recorded
by a high-speed camera, and a microphone recorded acoustic signals in the
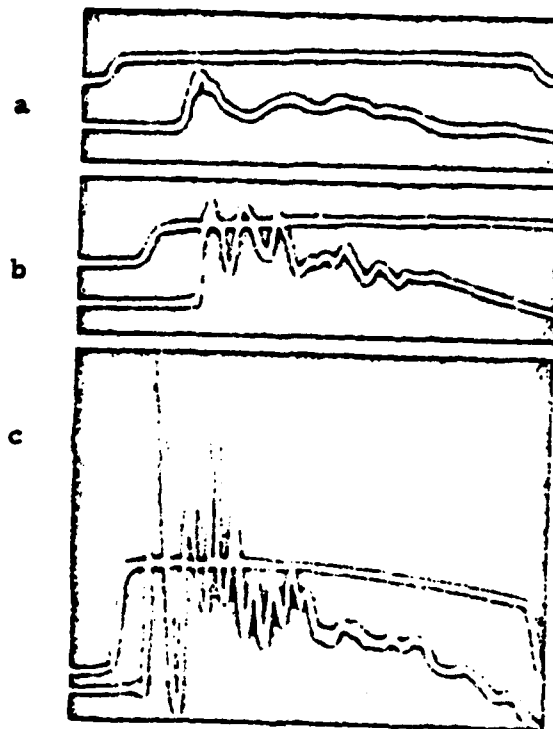air.

Fig. 1. Oscillograms of laser pulse (upper curve) and pressure signals and various radiation intensities. Scale - 100 μsec/division.

a - 2.2×10^5, b - 4×10^5, c - 10^6 w/cm^2.

Characteristic oscillograms of pressure signals in the power density range of 2.2×10^5 - 1×10^6 w/cm^2 are shown in Fig. 1. At a given laser pulse duration, pressure pulsation is seen to have a threshold character, in which the pulse period and time lag γ between the onset of radiation interaction and the time of the first pressure peak both decrease with increase of radiation intensity I. Taking the time of sound propagation in the mercury column Δt = 13 μ sec, the authors find the relationship $\tau(I)$ to be in nearly inverse proportion.

Golubev, G. P., I. Ya. Ivantsov, A. M.
Pavlov, A. K. Semenov, and V. P. Filippov.
Study of pressure from the action of laser
radiation on metals. ZhTF P, v. 1, no. 15,
1975, 711-713.

Pressure dynamics on metal targets were investigated,
resulting from laser irradiation in a 10^{-2} torr vacuum and in ambient air.
Laser pulses with $\lambda = 1.06\ \mu$, energy $= 0.5$ j and duration $= 50$ ps were
focused by a lens with $f = 5$ cm on the target surface to form a spot of
0.5 mm diameter. Pressure measurement was by piezoceramic and quartz
detectors with time resolution $= 10^{-8}$ sec. Targets used were Al, Zn, Cu,
and W of 50-500 μ thickness. Pressure signals and laser pulses were
simultaneously recorded by oscillography, as illustrated in Figs. 1 and 2
for a zinc target. Amplitudes of pressure signals at a power density of

Fig. 1. Laser pulse (lower curve)
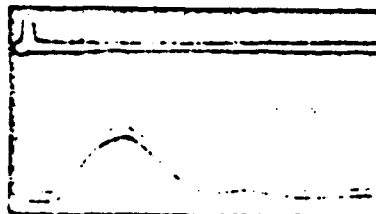pressure signal (upper curve), in
vacuum.

Fig. 2. Laser pulse (upper curve)
and pressure signal (lower curve),
in air.

5×10^9 w/cm^2 amounted to 500 and 1000 kg/cm^2 in vacuum and in air respectively.

In the case of vacuum irradiation, pressure on the target
surface bears a linear relationship to incident flux density in the range of
10^8-10^9 w/cm^2. At densities higher than 10^9 w/cm^2, the pressure starts
decreasing, which is probably due to target shielding by metal vapor. In
the case of an air ambient, pressure at 10^8 w/cm^2 is practically independent
of target materials; here the density of 10^8 w/cm^2 is close to threshold. At
densities greater than 10^8 w/cm^2, pressure signals vary linearly with density.
The observed effects in air are explained by assuming that pressure signals
originate due to shock waves from low threshold breakdown of air near the

10

target, and this results in the surface shielding of targets from incident
laser pulses.

Lokhnygin, V. D., and A. A. Samokhin.
Shielding of a metal surface under the action
of laser radiation. ZhTF P, v. 1, no. 16, 1975,
749-752. (RZhF, 12/75, #12Ye1106). (Translation)

Shielding of metal targets (Al, Pb) was investigated by a
technique of transverse probing of the absorbing region using a c-w He-Ne
laser. Average power density on the target surface at spot dimensions
of 1-2 mm^2 was 2×10^7 w/cm^2 or above. Target thickness varied from
0.08 to 0.8 mm. Propagation velocity v of the shielding cloud was considerably
smaller than the velocity of sound, and for t < 1/v, disturbance of the probe
beam was quite small.

The maximum value of the normal scattering velocity
component of the liquid phase, estimated from the increase of shielding
time lag with increase of distance 1, equalled 1.5×10^3 and 4×10^3 cm/sec
for Zn and Pb targets, respectively. The minimum value of this velocity,
which determines shielding persistence after termination of the laser pulse,
was lower by an order. The results confirms the contribution of liquid
metal drops to shielding from destructive radiation.

Agashkov, A. V., G. D. Ivlev, and V. N.
Chizhevskiy. Calculation of metal heating by
pulsed laser radiation. IN: Sb. Kvant. fiz.
elektronika. Minsk, 1975, 89-90. (RZhF,
18Ye, 1/76, #1Ye990). (Translation)

A solution is obtained to a nonstationary one-dimensional
problem of thermal conductivity, which describes metal heating by a series of

laser pulses. Equations are obtained for calculating temperature vs. depth during series of pulses, which are approximated by a step function of time. A simple formula is derived based on the time interval between free-running pulses, which gives changes in surface temperature.

Devyatykh, G. G., B. A. Nesterov, G. A. Maksimov, and N. V. Larin. Structure of halo, formed by laser pulses on a target surface. ZhTF P, v. 1, no. 7, 1975, 318-320. (RZhF, 10/75, #10Yel031). (Translation)

The composition and structure of the aureole, formed around a target crater as a result of Q-switched laser pulses, are studied by electron microscopy and electronography. It is shown that aureoles for the various targets (Si, Cu, Sn) consist of amorphous films and polycrystalline deposits. The aureole material is that of the targets.

Samsonov, G. V., A. D. Verkhoturov, Ye. Ya. Tel'nikov, L. A. Kravchuk, and A. V. Vasil'yev. Study on the effect of the type of transition metals of IV-VI and VII groups during their treatment by highly-concentrated energy flux. IN: Sb. Novyye metody ispytaniya i obrabotki materialov. Minsk, Nauka i Tekhn., 1975, 215-221. (RZhMetal, 12/75, #121479). (Translation)

Relationships are investigated of the erosion of transition metals of the IV-VI and VII groups during electron beam, spark and laser treatments. It is shown that there is a general tendency towards an increase of erosion resistance in the above metals as their valence electrons increasingly appear in a stable configuration.

Anisimov, S. I., V. A. Gal'burt, and V. I. Fisher. Structure of the absorption zone under the action of laser radiation on metals. ZhTF P, v. 1, no. 7, 1975, 321-325. (RZhF, 9/75, #9D951). (Translation)

Studies are made of the dispersion dynamics of a dense metal vapor which absorbs laser radiation. The recoil pulse, reflection coefficient and effective specific energy of the metal vapor are calculated as a function of laser pulse duration and radiation intensity. Results are described of calculating the optical absorption zone in a dense metallic plasma.

Gagarin, A. P., V. V. Druzhinin, N. A. Raba, and S. V. Maslenikov. Destructive action of thermal radiation from a laser erosion plasma under extended shielding conditions. ZhTF P, v. 1, no. 7, 1975, 311-315. (RZhF, 9/75, #9D952) (Translation)

Studies were conducted of the expansion rate of an Al vapor boundary under the action of laser radiation. The rate was estimated from the evaporation time of Al layers, separated by dielectric layers. It is shown that after evaporation of the first Al layer and formation of a shielding shell with transparency less than one percent, radiation power density at the barrier decreases only by 2.3 times. It is concluded that the destruction of the barrier after initiation of shielding takes place under the action of thermal radiation from the flare, which is heated by laser radiation.

Rykalin, N. N., A. A. Uglov, M. M.
Nizametdinov. Features of laser radiation
interaction with materials at high ambient pressures.
ZhETF, v. 69, no. 2, 1975, 722-732.

Experiments are described on the interaction of laser
radiation with various metals and dielectrics at ambient pressures from
1-140 atm. The radiation source was an Nd glass laser with pulse duration
τ of 0.8 msec; pulse energy was varied from one to tens of joules; lens
focal length = 150 mm; flux density = 10^6 to 10^7 w/cm^2 at spot radii of
0.03-0.05 cm. The laser pulse was of spiked structure with a nominal
peak duration of 1 μsec. Targets used were molybdenum and stainless
steel plates of 1-2 mm thickness as well as high temperature 22 Kh
ceramic and textolite plate. Tests were done in a nitrogen atmosphere.

Experimental results showed that increase of ambient
pressure in the range of 30-100 atm at flux densities of 10^6-10^7 w/cm^2 leads
to nearly complete shielding of target surfaces by plasma clouds. The
primary mechanism in forming a laser radiation absorption region in a cold
gas at high pressures near targets is thermoemission (during slight
vaporization) and breakdown in evolved vapors during strong vaporization.
The main mechanism for sustaining plasma clouds at flux densities of
1-10 Mw/cm^2 is a slow combustion.

The authors note that periodic changes in plasma brightness
after the end of radiation interaction in dielectrics can be correlated with
energy release from chemical reactions, whose development is determined
by the time required to attain a temperature which in turn depends on
particle dimensions. Plasma parameters are plotted as functions of target
material and ambient pressure. The authors include discussion of the
interrelation of target material, incident flux density and ambient gas
pressure.

Kozlova, N. N., I. E. Markovich, I. V. Nemchinov, A. I. Petrukhin, Yu. Ye. Pleshanov, V. A. Rybakov, and V. A. Sulyayev. Experimental investigation of laser radiation interaction with obstacles in air. KE, no. 9, 1975, 1930-1941.

Effects of laser radiation on aluminum targets in air were experimentally observed. The radiation source was a Q-switched Nd laser with bell-shaped pulses of 1μsec duration and energy up to 30 j at spot diameters of 5-8 mm. Tests were conducted with flux densities of 10 to 300 Mw/cm^2 under conditions of uniform spot illumination. Measurements were taken of the shape of flare formation, rate of plasma front and shock wave propagation, brightness temperature, and pressures at various moments of time.

It was observed that at flux densities up to about 100 Mw/cm^2, absorption waves are generated at the forward flare boundary, which is opaque to incident radiation, and transparent shock waves propagate in front of the absorption waves. The expanding plasma acts as a plunger on the surrounding cold layers. At higher flux densities, a transition is noted into an explosive regime, which is a complex process resulting from radiant energy transfer processes from the continuous hot plasma spectrum. When the flare front expands to a distance on the order of the spot diameter, a two-dimensional motion of surrounding air commences. Graphical data and photos of shock wave and flare development are included.

Arzuov, M. I., A. I. Barchukov, F. V. Bunkin, V. I. Konov, and A. A. Lyubin. Violent surface oxidation of metals and accompanying phenomena under the action of continuous CO_2 laser radiation. KE, no. 8, 1975, 1717-1724.

The action of c-w radiation from a 1-kw CO_2 laser on bulk metal targets was experimentally investigated in air and oxygen ambients at

15

pressures of 10^{-3} -1 atm. Targets used included refractory metals (tungsten, molybdenum), low-melting metals (aluminum, copper) and gold. During irradiation, targets were heated up to temperatures yielding vigorous surface oxidation, i.e. burning of the metals. A brief description is given of the experimental procedure and the observed results are analysed and interpreted. Figs. 1 and 2 show examples of tungsten exposure.
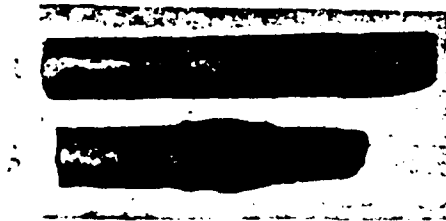

Fig. 1. Tungsten target of 0.5 cm radius, before (a) and after (b) irradiation.

Fig. 2. Frame sequence of flare development on a tungsten target. Laser beam incident from the right, frames at 1 millisec intervals.

Experimental observations may be summed up as follows:

1. During irradiation of metal targets, an effective mechanism is observed of metal destruction, which is not connected with melting or evaporation of the metal. The temperature T^* at which this surface burning takes place depends on the partial pressure of oxygen and type of metal. For refractory metals this T^* in air is less than the melting point Tp, so that destruction of these metals under radiation takes place in the solid phase by surface burning. In the case of low-melting metals, $T^* > $ Tp, so that metals of this type first melt, then burn.

2. Experiments showed that irradiation of metals in oxidizing media leads to significant increase of their absorptive power. At temperatures $T < T^*$, the increase is gradual, while for $T > T^*$ the absorptive power increases in a discrete stepwise manner.

3. In specific conditions of oxidation in air, irradiation leads to initiation of optical discharge near the target surface, which is maintained by surface burning.

Results of the present work were presented by Barchukov et al. at the Conference on the Coherent and Nonlinear Optics in Tashkent in 1974.

Kozlova, N. N., A. I. Petrukhin, and V. A. Sulyayev. <u>Experimental study of the onset of evaporation and formation of a plasma layer during the action of laser radiation on metals in different gases.</u> KE, no. 7, 1975, 1390-1394.

Onset of evaporation and formation of a plasma layer over a metal target were experimentally investigated during the action of Nd laser pulses of $1\,\mu$sec duration. Targets studied were Al and Bi, and the gaseous media were air, argon and helium. The experimental setup is shown in Fig. 1. Oscillograms and teplergram were recorded, which showed the
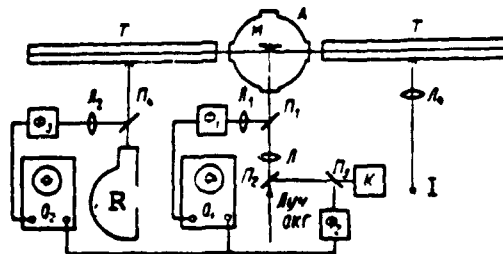

Fig. 1. Experimental sketch.

$L-L_4$ - lenses; P_1-P_4 - splitters; I - light source; T-Tepler device; F_1-F_3 - photoelements; O_1-O_2 - oscillographs; K - calorimeter; M - target; A - test chamber; R - delayed photorecorder.

initial stages of vapor scattering and formation of shock waves. Results from one experimental series with an Al target are shown in Fig. 2. Table 1 lists the results of investigations in different media.
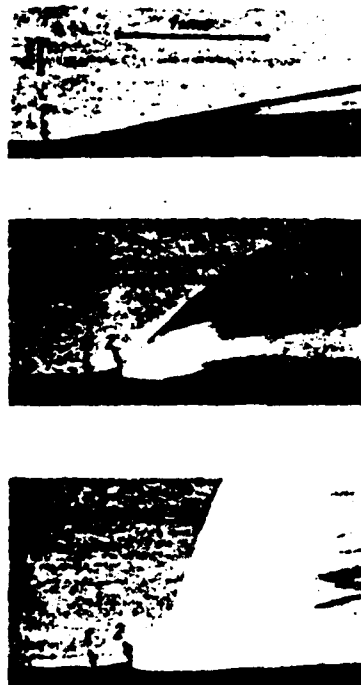

Fig. 2. Results with Al target.

1 - evaporation start; 2 - flare start. Densities from top are 5. 5, 16. 4 and 94 j/cm^2.

Table 1. Results of experiments in different media.

Target material	q'_o Mw/cm^2	E'_o j/cm^2	q_{cr} Mw/cm^2	E_o j/cm^2
Al - air	10.4 ± 0.7	0.8 ± 0.1	50 ± 5	5.0 ± 0.5
Al - argon	10.4 ± 0.7	0.9 ± 0.1	60 ± 5	6.5 ± 0.5
Al - helium	-	-	60 ± 5	6.0 ± 0.5
Bi - air	5.0 ± 0.7	0.45 ± 0.15	22 ± 5	2.1 ± 0.5
Bi - argon	5.2 ± 0.7	0.5 ± 0.15	25 ± 5	2.6 ± 0.4
Bi - helium	-	-	26 ± 5	2.8 ± 0.5

(Prime notation signifies evaporation onset.)

Analysis of the results shows that the velocity of shock waves generated by vapor before the flare did not vary appreciably during the experiments. For Al, the average value of shock wave velocity in air was 1.2 ± 0.1 km/sec, which corresponded to a pressure behind the shock wave of 14.4 ± 3 bar. Hence during the time from evaporation onset to the formation of shock waves, i.e. $0.2 - 0.3 \mu$sec, waves traveled only about 2-3 mm from the target. The picture was therefore close to two-dimensional. The values obtained for critical flux density q_{cr} required to form a plasma layer are compared with those of previous studies, and are found to be in good agreement.

Tananykhin, A. A., N. A. Zatenko, and K. I. Kononenko. Coefficients of reflection and transmission in thin films under laser radiation. Vestn. Khar'kov un-ta no. 130, radiofiz. i elektron no. 4, 1975, 122-124. (RZhRadiot, 3/76, #3Ye252) (Translation).

Coefficients of reflection and transmission of thin metallic films were measured during oblique incidence of laser radiation. Their relationships as functions of incident energy density and film thickness were obtained for Al, Ag and Cu films. Film thickness was measured in the range of 100-5000 Å and incident energy density was 0.1 to 2.4 j/cm^2.

Arifov, U. A., V. V. Kazanskiy, V. B. Lugovskoy, and V. A. Makarenko. Some features of emission pulses, induced by regular pulsations of ruby laser radiation. IAN Uzb, no. 4, 1975, 49-52.

Test results are described of an experimental study on various characteristics of emission current pulses, recorded in laser-irradiated tungsten targets. Experiments were done with a ruby laser, generating

19

trains of 30 regular spikes with a nominal width of 260 nsec. Maximum value of power density on the target surface was 7.4 Mw/cm^2. The target, a polycrystalline tungsten strip of 20 x 5 x 0.1 mm^3, was placed normal to the laser beam and 1.5 cm from a copper collector, which had an aperture for admitting the laser beam. Specimens were irradiated at two temperatures, 300° and 1200° K at a pressure of 10^{-6} torr.

Thermoelectronic emission recorded by the collector was observed only when the change in target surface temperature was less than 700° C. Oscillograph recordings of individual laser spikes and corresponding emission current pulses showed the latter to be both symmetric (Fig. 1, a) and asymmetric (Fig. 1, b) in shape.
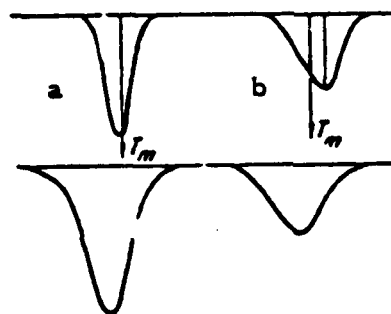

Fig. 1. Oscillograms of emission (top) and laser (bottom) pulses.

Absolute values were determined of the differential Δt between emission and laser peaks. It was found that the differential in the peak of symmetric emission signals $\Delta t = 1\pm2$ nsec, i.e. within measurement accuracy limits, the electron emission and laser peaks coincide. The value of Δt significantly fluctuates and its rms variance σ was 13 nsec, which in 5.5 times more than the differential between laser pulses, as obtained from calibration measurements. Measurement results of Δt and σ for symmetric (I) and asymmetric (II), current pulses are given in Table 1.

Table 1

Target temp. $^\circ$K	No. of peaks	Δt, nsec	σ nsec	$\Delta t/\Delta t$ calculated
I - Symmetric pulses				
300	29	0 ± 4	20	0
1200	19	4.6 ± 8	35	0.06
II - Asymmetric pulses				
300	25	23 ± 5	25	0.3
1200	13	63 ± 6	19	0.8

The authors conclude that symmetric emission pulses have specific features of a multiple-quantum photoeffect. No interpretations are however attempted on the asymmetric emission signals, which the authors describe as a complex problem.

Afifov, U. A., V. V. Kazanskiy, V. B. Lugovskiy, and V. A. Makarenko. Characteristics of negative charged particle emission, resulting from laser irradiation of tungsten. ZhTF, no. 2, 1976, 417-418.

The phenomenon of negative charged particle emission in the form of asymmetrical pulses from a laser-irradiated tungsten target is studied. The ruby laser used was operated in a regular pulsed mode with peak pulse duration = 0.25 μ sec, interval between peaks = 100 μsec, and peak power of 0.3 Mw. Radiation was focused on the target surface (1.5 cm from the surface) with a lens f = 70 mm. Radiation power density in the range 8-30 Mw/cm^2 was varied by means of neutral filters or by changing distance between target and lens. Emission and laser signals

were recorded by oscillograph S1-7; experiments were conducted in vacuum at 10^{-6} torr.
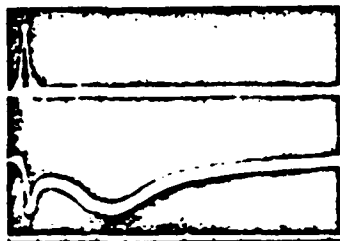

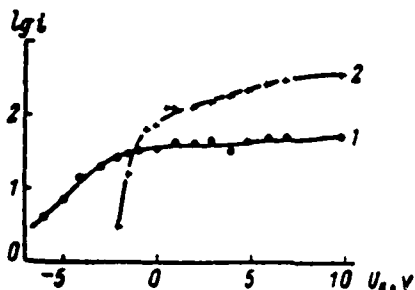Fig. 1. Oscillograms of laser (above) and emission (below) pulses.

Fig. 2. V-A characteristics of fast (1) and slow (2) components of emission pulse.

Oscillograms of laser and emission pulses and V-A characteristics of emission signal components are shown in Figure 1 and 2 respectively. V-A characteristics show two distinct components of emission pulse; namely *fast* and slow components. It is shown that these two fast and slow components represent electrons and negative ions respectively, and that their currents are proportional to the 4th and 7th powers of radiation power density respectively. Effective electron temperature, determined by method of counter potential, was found proportional to radiation intensity, and its value exceeded that of calculations by one order of magnitude.

In conclusion, it is mentioned that the authors have obtained data in a time-flight mass-spectrometer, which conform well to the present interpretation that the slow emission component is negative ion pulses. These pulses consist of large number of peaks with masses of 1, 3, 4, 16, 18, 35, 37, 42, 48, 64-80, 100-130, and others. Most intensive among them are chlorine ion peaks. Detailed methods and results of these investigations will be published by the authors later.

Dneprovskiy, V. N., and A. A. Shchuka.
Rhenium films, obtained by laser deposition,
and their properties. IN: Sb. Issled i
primeneniye splavov reniya. Moskva, Nauka,
1977, 166-167. (RZhMetal, 9/75, #9I727).
(Translation)

A method is suggested for obtaining rhenium films by
laser deposition which has several advantages: the possibility of depositing
films in evacuated vessels and in given gaseous media; the absence of a
preheater; shorter time of film deposition; economy in mass production,
and others. During experiments, pulsed laser radiation with energy of
100 j and duration of 10^{-3} sec was focused on rhenium specimens, with
vapor being deposited on glass, pyroceram or mica substrates as well as
on the cleavage surface of NaCl crystals. The films obtained had good
adhesion to their substrates and were of high optical quality; ρ for films
of 450-500Å thickness was 8.5×10^{-4} - 2×10^{-3} ohm x cm, and increased
with aging. Electronographic studies of the surface showed that the films
had a polycrystalline structure, and in time formed an oxide layer.

Rudnev, A. N., V. N. Sivers, and Ye. A.
Buznitskiy. Coagulation of free aluminum films
under the action of a laser beam. IN: Fiz.
elektronika Resp. mezhved. nauch.-tekhn. Sb.,
no. 8, 1974, 79-81. (RZhF, 4/75, #4Ye986).
(Translation)

The coagulation process of free polycrystalline aluminum films
of thickness ~ 1000 Å under the action of laser pulses with energy of 0.3
joule was studied by means of an electron microscope. Two types of coagulates
were detected: "islets", which have a textured structure, and "granules"
having a single-crystal structure. The degree of coagulation was experimentally
determined, which equalled 0.64 for granules and 0.49 for islets.

Larina, R. R., S. V. Makarova, L. I.
Mirkin, and L. V. Tuzov. Effect of laser
radiation on the dislocation structure of zinc.
IN: Tr. Kirg. un-ta. Ser. fiz. n., no. 6,
pt. 2, 1974(1975), 5-9. (RZhF, 18Ye, 1/76,
#1Ye992). (Translation)

The dislocation structure of Zn single crystals of 99.999%
purity was investigated following exposure to Nd laser pulses with energy =
20-30 j and duration = 10^{-3} sec on the (0001) plane, obtained by splitting
the crystal after cooling it in liquid nitrogen. Internal dislocation structure
was investigated by the method of cavity etching and chemical polishing at
a rate of 0.2 μ/sec. It was shown that a zone with increased dislocation
density in the form of a regular hexagon is formed around the crater, from
the top of which rays formed by etched cavities emerge. The sides of the
hexagon and the rays were parallel to the <1010> direction. During irradiation
by powerful focused pulses on the opposite side of the crystal, projections in
the form of tetrahedral pyramids were formed with slip planes <1122>;
however, the zone filled with deformed dislocations was circular, thus
confirming the crowdion mechanism of plasticity. At 77°C, the dimensions
of the deformation region were 2-2.5 times smaller. At 320°C slip systems
were indistinguishable. The depth of the zone with changes in deformation
structures equalled 100 μ.

Kovalev, V. I., V. V. Morozov, S. I. Sagitov,
and F. S. Fayzullov. Study of the radiation
resistance of gold coatings. KE, no. 7, 1975,
1527-1535.

A test to evaluate the damage threshold and determine optimum
fabrication parameters of gold thin films as optical reflectors is reported.
Effects of film thickness, substrate material, vacuum level during
deposition, deposition rate, and annealing were investigated as a function of
damage threshold of the gold layer exposed to pulsed CO_2 laser radiation.
The experimental setup for measuring threshold destruction of metallic
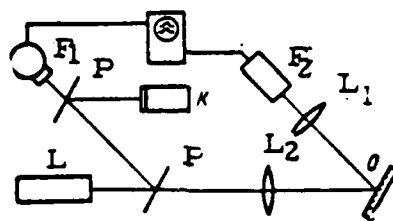reflector and films is shown in Fig. 1. The transverse-discharge CO_2

Fig. 1. Experimental sketch.

L - CO_2 laser; P - Plane-parallel NaCl plate;
F_1 - Hg-Cd-Te photodetector; F_2 - Photon drag
receiver; L_1, L_2 - NaCl lens; k - Calorimeter;
O - specimen.

laser had an output energy of 350 millijoule per single pulse, at a duration
of 200-250 nsec, and maximum laser output power was 0.5 Mw. The
experimental measurement procedure and the vacuum deposition technique
are briefly described. Fig. 2 shows film damage for four different substrates,
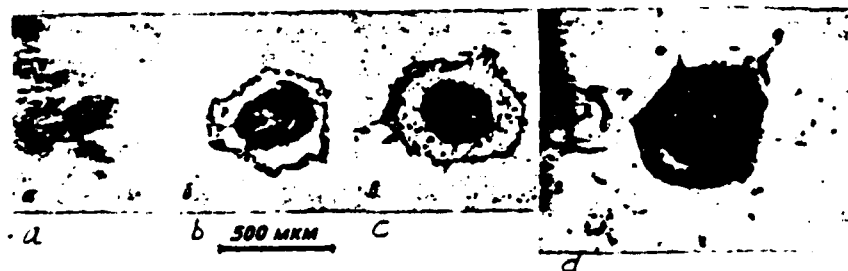but does not relate them to laser parameters.

Fig. 2. Laser destruction of a 0.28 micron gold
film on substrates of a) copper, b) nickel, c) titanium
and d) glass.

The tests show that with careful depositing of gold films
corresponding to optimum selection of substrate and film thickness, it is
possible for their optical strength to approach that of the solid metal. The
strength of gold film increases with thickness, up to an incident power
density of 35 ± 12 Mw/cm^2 at the reflector surface, where breakdown occurs
in metal vapors and in contaminants, and the radiation is absorbed by the
resulting plasma; this effect sets the upper limit of optical strength. A laser

cleaning effect is observed on the surface of the metallic reflector, as well as on transparent IR materials; this acts to retard plasma generation near the surface.

The use of complex substrates such as the glass + metal layer for laser mirrors thus can eliminate some of the difficulties of forming and polishing of massive metallic reflectors, while nearly duplicating the optical performance of bulk metal. However, further refinement is needed in the manufacturing technology of film reflectors for increasing their optical strength.

Kovalenko, V. S., V. S. Chernenko, N. I. Prikhod'ko, and A. I. Strizhak. Laser strengthening of contact surfaces of metal seals. EOM, no. 6, 1975, 77-79.

Results are described of experimental studies conducted in Kiyev Polytechnical Institute on laser hardening of contact surfaces of metal valve seals. The specimen used was a valve seat gasket made of stellite (1.6 - 2.3% C; 1.5 - 2.5% Si; 26 - 32% Cr; 59 - 65% Co; 4 - 5% W; remainder Fe), which was irradiated with an SLS-10-1 laser system for which the following operating conditions are given: pump voltage = 800-1000 v; pulse duration τ $\approx$ 4 msec; number of pulses = 1-8; focal length F = 37 mm; displacement of the target surface relative to the focal plane ΔF = 0.05-0.1 mm.
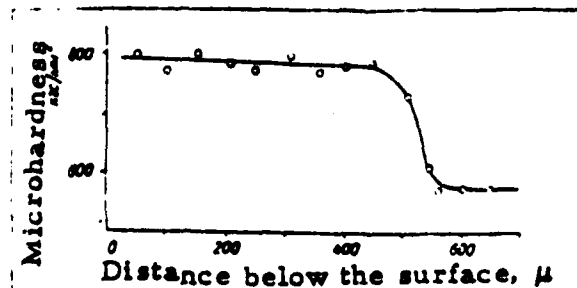

Fig. 1. Microhardness of stellite in the laser-exposed zone.

Microstructural analysis and microhardness measurement of the treated specimen showed that the structure of the specimen in the laser-heated region differed considerably froms its initial structure, particularly with regard to its fine dendritic structure and large number of highly scattered carbide particles.

Hardness of the irradiated surface was 150 - 200 kg/mm^2 greater than that of the initial stellite. The cited irradiation parameters, using a pulse energy of 8 joules, were found to provide the best hardening characteristics. Testing of the laser-hardened valve seals showed that they were very stable and had 2 to 3 times the normal operating life of untreated stellite seals.

Plyatsko, G. V., A. I. Porter, G. A. Preys, and M. I. Moysa. Effect of the laser treatment of steel on its durability in a corrosive medium. FiKhMM, no. 5, 1975, 91-94.

Tests have shown that laser processing of some metals can increase their wear resistance in an aggressive medium by 2 or 3 times. A recent study to systematically establish the effect has been reported, based on laser-treated type 45 steel in sliding contact with other steel, cast iron and bronze specimens. The authors detail the conditions for which the laser-treated steel shows enhanced wear properties, and in some cases not, such as when paired with bronze specimens. Test data were recorded in both acid and alkaline media. No details of the laser treatment are given, however.

Alebastrova, Ye. P., L. I. Mirkin, and Ye. F. Smyslov. <u>Structure and hardness of materials, obtained during treatment of powders by shock waves and laser beam.</u> DAN SSSR, v. 225, no. 6, 1975, 1304-1307.

Results are described of studies on the possibility of using shock waves and laser radiation for treating metallic powders to obtain hardened materials. Data are included on the resulting changes in their composition, structure and properties. Specimens studied were Al, Ni, Mg, carbonyl Fe, $Mo, SmCo_5$ and others. In the laser part of the test, radiation was with a GOS-30M laser at $\lambda = 1.05\mu$, energy = 30j and pulse duration = 10^{-3} sec.; beam defocusing was 30%. Experimental schemes used prevented scattering of powders during evaporation. Specimens after being treated as above were subjected to structural investigations, including metallography, microhardness, and x-ray spectral analysis.
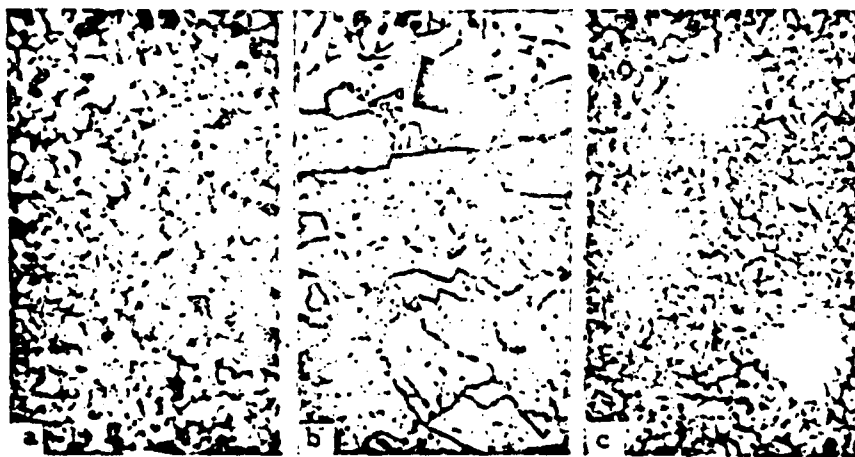

Fig. 1. Microstructure of carbonyl Fe specimen, 450X. (a) initial; (b) after irradiation; (c) after shock wave treatment.

Table 1. Results of x-ray structural investigations and microhardness of carbonyl Fe after laser and shock wave treatments.

Treatment	Width of x-ray lines, mrad.		Block size, A	Micro-distortions, $\times 10^3$	Micro-hardness, kg/mm^2
	110	220			
None	1.30	1.90	960	0.17	
Shock waves	1.90	16.30	730	2.46	192
Laser radiation	2.00	9.70	620	0.44	175

Fig. 1 shows microstructures of carbonyl iron, and results of their x-ray structural analysis are given in Table 1. It can be seen that for specimen blocks obtained by shock waves, the number of micro-distortions in the lattice increased by more than one order, as compared to the initial specimen. This increase in microhardness, resulting from strong shear at the shock wave front, was found responsible for the observed microhardness. Increase of the explosive power led to an increase of block size, and to decrease of microdistortions and microhardness, connected with the recrystallization of the substance.

The laser irradiation effect was characterized by large metallographic grain size and a smaller number of microdistortions in the lattice (Fig. 1b), which is associated with the absorption of optical energy and fusion of the substance. In the case of $SmCo_5$, its behavior under shock wave and laser treatments was found quite different. The microhardness of $SmCo_5$ after shock wave treatment was 640 kg/mm^2 as compared to fused $SmCo_5$, the hardness of which equals 246 kg/mm^2. Laser irradiation of $SmCo_5$ led to the formation of Sm_2Co_{17} compound, with a hardness of 210 kg/mm^2.

Alekseyev, P. A., B. M. Zhiryakov, and A. K. Fannibo. <u>Dynamics of the stressed state of a substance under laser radiation.</u> KE, no. 8, 1975, 1813-1815.

Results are described of experiments on the action of laser radiation on ED6-MA (not identified) and other metal specimens, based on the method suggested by the authors in an earlier work (KE, no. 2, 1975, 1019). Irradiation was done by free-running pulses with spiked structure, as well as by bursts of 10-15 giant pulses, obtained by passive Q-switching of the resonator. In the case of spiked pulses, instantaneous flux density q_o on the target surface reached 10^8 w/cm^2, with an average flux density over the total pulse $q = 3$-4×10^6 w/cm^2; in the second case instantaneous flux density reached 2×10^9 w/cm^2 during a single giant pulse of 60 - 70 nsec duration.
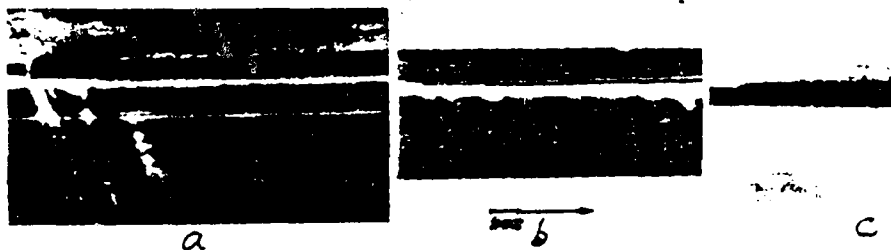

Fig. 1. Photographs of laser radiation interaction with various targets.

(a) ED6-MA irradiated by single giant pulses;
(b) ED6-MA irradiated by burst of pulses;
(c) Pb irradiated by single giant pulses.

Direct action of single giant pulses on photoelastic ED6-MA targets generated acoustic oscillations on the target, together with scattering of liquid phase and solid particles (Fig. 1a), when flux density exceeded the threshold value (5×10^8 w/cm^2 for ED6-MA). Solid particles were characterized by considerable asymmetry; this is seen from changes in vertical dimensions of shadows in the Fig. 1 photographs. Scattering speed of ejecta was in the range of 20-800 m/sec. In some cases particle scattering and generation of acoustic waves were observed with some delay after the action of pulses; this delay was on the order of 1 μsec. Generation and propagation of shock

waves with initial velocity not less than 4.4 km/sec was observed simultaneously with the particle scattering in the specimen. The wave attenuated 0.3-0.5 μsec after its generation at a depth of 1-1.5 mm, below which it converted to linear acoustic waves.

The action of spiked pulses on the above specimen caused scattering of a large number of condensed particles with velocities of 40-150 m/sec and sudden development of a shadow near the surface (Fig. 1b). A similar effect, but without shadows or condensed particle scattering, was also observed in the case of giant pulses with flux densities below 5×10^8 w/cm^2.

In the case of other metal targets (Cu and Pb in the present experiment) giant pulses generated linear and lateral acoustic waves, with lateral waves attenuating faster than linear. It was seen that the surface of irradiated metals broadened [sic] in the direction of incident radiation (Fig. 1c). The maximum speed of surface broadening in Pb was 700 m/sec. This process was accompanied by scattering of large (up to 100 μ) and small fusion metal drops. A similar effect, i.e., scattering of fused metal drops, was also observed in the case of irradiation by spiked pulse, however a small time lag (up to 3 μsec) was noted between the initiation of scattering and pulse start; scattering coincided with the generation of acoustic waves.

2. Dielectric Targets

Yeron'ko, S. B., G. T. Petrovskiy, A. V.
Shatilov, A. K. Yakhkind, and L. V.
Aleksandrova. Strengthening of a glass
surface under repeated optical loading. OMP,
no. 1, 1976, 35-38.

The authors and co-workers have made a number of
studies recently to determine optimum ways of raising the damage thresh-
old of laser optics. Experience shows that the entrance (or exit) face
of an element passing the laser beam is the typical weak spot, evidently
because in forming these surfaces, even with refined polishing techniques,
there still remains a residue of discontinuities, inclusions and the like
which become the focal point of laser breakdown. The problem reduces
to seeking increasingly sophisticated methods of surface treatment so
that the breakdown threshold can be raised to a useful limit.

Among the methods studied by the Russian team, in addi-
tion to deep grinding and polishing, have been chemical etching, ion
polishing, and most recently a chemical processing of the glass face to
add a surface film. In the presently reported tests the film was of
porous silicon dioxide with a sulfur hexafluoride filler to provide max-
imum surface smoothness. Specimens of barium silicate and aluminum
borosilicate glasses thus treated were exposed to varying numbers of
shots from an Nd glass laser, focused at random points over the specimen
faces. The pulse energy level was held within a range of 90-95% of
breakdown threshold, the criterion for breakdown being evidence of
plasma generation at the target face.

The results are given as probability functions, rather than
in absolute terms. Thus in barium silicate glass the probability of break-
down in 4000 shots, using laser energies at 95% of threshold, drops to
a value of 0.69 in coated specimens, as opposed to an 0.9 breakdown

probability for uncoated mechanically polished specimens. The SiO_2 + SF_6 coating method is hence credited with raising both absolute break-down threshold as well as substantially increasing the life expectancy of the laser-exposed glass.

Gridin, V. A., V. A. Krotov, and A. N. Petrovskiy. <u>Destruction of KDP crystals by ultrashort laser pulses.</u> KE, no. 2, 1976, 311-315.

Destructive action of ultrashort laser pulses on nonlinear KDP crystals was experimentally investigated. Tests were done with a laser operating in single-mode regime at $\lambda_1 = 1.06\,\mu$ and $\lambda_2 = 0.53\,\mu$. Target dimensions were 15 x 15 x 20 mm, with radiation focused in the specimen volume by lenses with f = 12 to 75 mm. The character of destruction and damage threshold were observed under different conditions, as functions of crystal orientation, lens focal distance, laser radiation wavelengths and incident radiation density on the specimen.

The authors introduce a novel double-frame pulsed holography method for studying the damage process. Fig. 1 shows the functional sketch, and its procedure is decribed briefly.
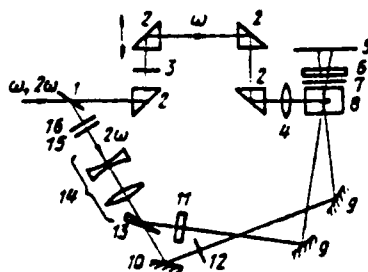

Fig. 1. System for obtaining destruction holograms.

1- beam splitter; 2- prism; 3-light filter; 4-lens with f = 36 mm; 5- photo plate; 6- Fresnel prism; 7- light filter; 8- specimen; 9,10- mirrors; 11- glass plate; 12,15- neutral light filters; 13-wedge; 14- telescope; 16- light filter.

33

The tests show that the damage mechanism of KDP crystals has a discrete character which is independent of crystal orientation as well as of the lens focal distance, although damage threshold does rise with increase in focal distance. On changing wavelength from 1.06 μ to 0.53 μ, the character of destruction was practically the same, but the damage threshold decreased by about one order.

Studies of the dynamics of destruction development with the pulsed holographic method at energies above threshold showed that destruction occurs on both sides of the focal plane. The rate of damage propagation in the direction of the laser beam was estimated to equal 1.6×10^{10} cm/sec. Fig. 2 gives typical reconstructed holograms of a damage sequence.
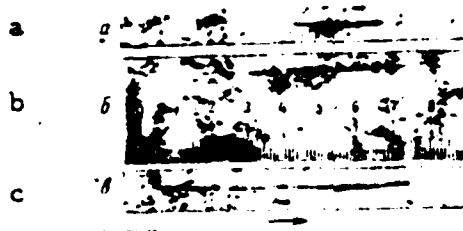

Fig. 2. Reconstructed hologram of laser damage to KDP crystal.

Frame (b) follows (a) by 9.7 picosec.; (c) is after passage of the laser pulse. Arrow shows beam direction.

Lokhov, Yu. N., V. S. Mospanov, and Yu. D. Fiveyskiy. Thermal stresses in the surface layer of a transparent solid dielectric. FikhOM, no. 1, 1976, 160-162.

This article gives a theoretical study on the kinetics of thermoelastic stresses developing on the surface layer of a transparent solid dielectric, taking into account specific laser radiation absorption

at the entrance region. It is assumed that the dielectric occupies the
half space $z \geq 0$, and that collimated single laser pulses impact its
surface with a Gaussian radial distribution of intensity. Investigation
of thermoelastic stresses shows that considerable compression stresses
are developed along the laser beam axis, taking into account surface
absorption of energy and absorption resulting from avalanche electron
multiplication.

An expression is derived for the maximum compression
stress σ_{max} , when the surface temperature reaches its melting point.
Numerical calculations under the assumed conditions show that σ_{max}
for sapphire equals 20 kbar, which is enough for mechanical destruction
of the surface. Estimated values of σ_{max} as well as the nature of stress
distribution in the present work agree well with the experimental
results of Fersman et al. (ZhTF, no. 5, 1970, 1084), where stresses
were determined based on measurement of refraction coefficient of
the material. Compression stresses, as in the cited work, were found
to concentrate near the specimen surface and not along the beam channel.

Kikin, P. Yu. <u>Effect of diffraction from internal
fractures on end-face damage of ruby crystals.</u>
KE, no. 10, 1975, 2348-2350.

This work presents further investigations of the fact that
Fresnel diffraction from blocks and slip planes can cause internal
destruction as well as end surface damage in a ruby crystal. Experi-
ments were conducted on ruby with existing internal damages or in which
internal damage centers (diameter 0.3 - 1 mm) were artificially generated
in the specimen at a distance 8-10 mm from the end surface near the
axis. Ruby specimens were rods of 6.5 mm diameter and 80 mm long.
Cr^{+3} concentration was 0.18-0.25%. Experiments were conducted in
a mechanical Q-switched regime with radiation energy of 0.2 j and pulse
duration of 30-70 nsec. The experimental sketch is shown in Fig. 1.
Image of the crystal end surface was taken on black photographic
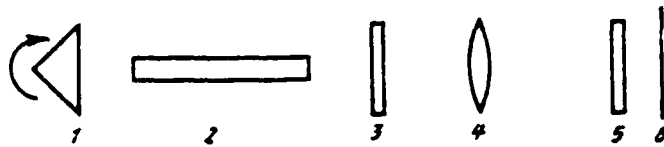paper, 6 (scale 1.1).

Fig. 1. Experimental sketch

1- Q-switch; 2- ruby crystal with damage;
3- resonator stop; 4- lens; 5- neutral filter;
6- black photo paper.

It was observed that the laser exposure caused destruc-
tion of the ruby crystal end surface, which was located opposite to the
existing internal damage region at 8-10 mm from the end. The end-
surface damage was in the form of burn-outs, having discrete cuts and
points located over a contour, the diameter of which equalled the diameter
of internal damage centers. Figure 2 shows the damage at the end
surface of a crystal specimen. Study of the end image on the photo film

Fig. 2. Destruction at the crystal end
surface. X220.

showed that discrete burn-out parts of the film correspond to the internal
damage location and the location of these parts corresponds to the
destruction pattern at the ruby end surface. The author notes that the
burned areas of the photo film are the result of the first maximum of
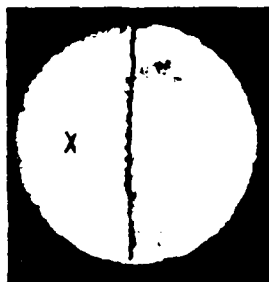Fresnel diffraction.

36

Fig. 3. End surface damage from diffraction of
a razor blade. (x- left side, covered by blade.)
X10

A second series of experiments was similarly conducted
to study the effect of diffraction from an opaque shield in damaging the
end surface. In this case a thin razor blade was placed 10 mm from
the crystal end surface, thus obscuring half the end face. The end
surface was found to be damaged along the blade line in the form of
minute burn-outs, located along the line of first maximum of Fresnel
diffraction (Fig. 3). It is thus shown that Fresnel diffraction from
inhomogeneities during prolonged operation of a ruby laser in a Q-
switched regime can cause damage at the end surface even at low
energies.

Zapechel'nyuk, E. F., B. S. Mikhaylov,
and R. B. Tagirov. Emission of neutral
molecules and electrons from a dielectric
surface under laser radiation. KE, no. 12,
1975, 2614-2615.

A study is reported on the emission kinetics of neutral
gas molecules from the surface of laser-exposed molybdenum glass.
The source was an Nd glass laser operating in a free-running regime
at a density of 2×10^4 w/cm^2. The unfocused laser beam of 5 mm
diameter was directed on the glass extension of a standard ionizing
manometer tube with a vacuum not less than 10^{-6} torr, causing desorp-
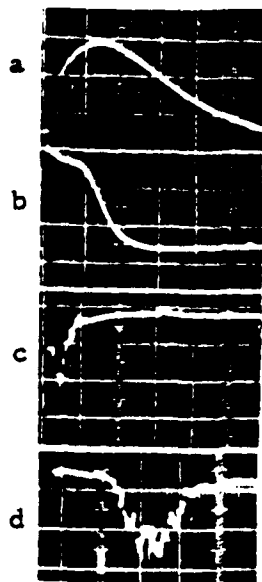tion of molecules from the inner glass surface. Fig. 1a shows laser

Fig. 1. Oscillograms:

(a) laser radiation pulses, (b) particle emission in 1st irradiation, (c) particle emission in 4th irradiation, (d) electron emission. Scale: (a); (b), (c) - 100 μsec/division, (d) 50 μsec/div. Zero line is located at the bottom for (a) and on the top for (b), (c), (d).

pulses recorded by a photoelement while Fig. 1b shows current pulses, corresponding to desorption kinetics, recorded by oscillograph at a time resolution of 10^{-5} sec.

Multiple irradiation of the same portion of the glass surface resulted in a sharp drop in particle emission, which soon reached a constant value after a few pulses (Fig. 1c); further irradiation resulted in change of emission kinetics and particle emission assumed a spiked character (Fig. 1d). It is shown that this spiked emission was in fact electrons and not charged particle emission. The results show that electron emission accompanies and even somewhat precedes the desorption of neutral molecules.

38

Makshantsev, B. I., and A. A. Kovalev.
Action of laser radiation on solid transparent
dielectrics. KE, no. 7, 1975, 1552-1554.

Based on fluctuation theory, relationships have been
previously developed for the breakdown power density q_p of laser
radiation as a function of focal spot diameter, d. However, a series
of experiments have shown that the value of q_p depends not only on
diameter d, but also on laser pulse duration τ, which was not taken
into account in the cited theory. The present brief work factors the
effect of pulse duration into expressions for q_p. Expressions are ob-
tained by means of which it is shown that the relationship of q_p at small
durations takes the form $q_p \sim \tau^{-1}$. With increased pulse period the
value of q_p thus decreases and is correspondingly less dependent on
time.

Kovalev, A. A., B. I. Makshantsev, B. F.
Mul'chenko, and N. F. Pilipetskiy. Depen-
dence of the destruction threshold of plexiglass
on the duration of laser interaction and dimen-
sions of the irradiated zone. ZhETF, v. 70,
no. 1, 1976, 132-140.

Experiments are described which were designed to
study the spot-dimension and time dependence of the damage threshold
of plexiglass. Specifically, the time at damage onset was correlated
with threshold power density. The target material used was poly-
methylmethacrylate (PMMA). The experimental setup is shown in
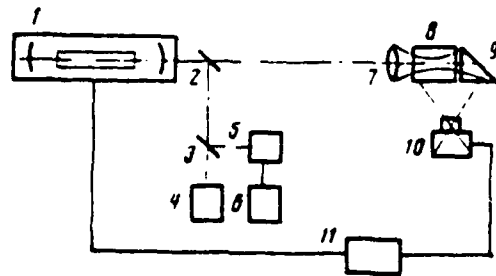Fig. 1 and its procedure is described briefly. The radiation source

Fig 1. Experimental sketch.

1- Ruby laser; 2,3- splitters; 4- energy
measuring device; 5- photoelement;
6- oscillograph; 7- lens; 8- specimen;
9- rotating prism; 10- high-speed SFR
camera; 11- synchronising and control-
ling unit for SFR and laser.

used was a ruby laser, operating in a quasistationary regime with
smooth pulses having uniformly distributed power density over
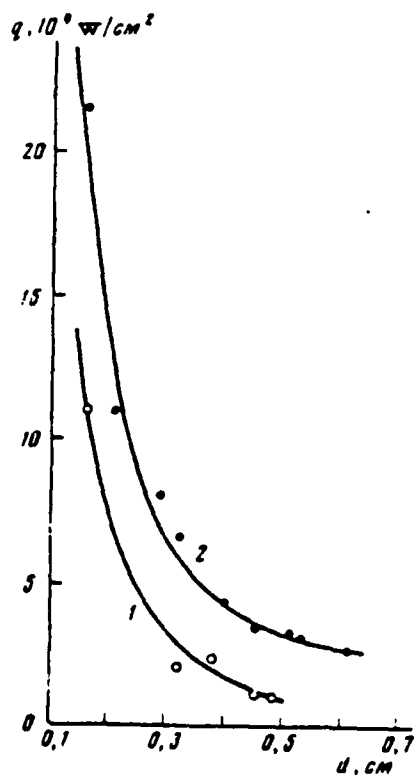the beam cross-section, and duration $\tau = 10^{-3}$ sec.

Fig. 2. Breakdown power
density q as a function of the
diameter of irradiated zone, d.
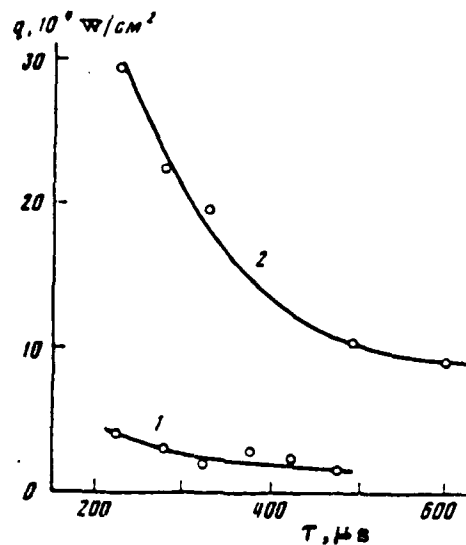
1- τ = 500 msec; 2- τ = 275 msec.

40

Fig. 3. Power density as a function of pulse
duration τ.

1- d = 0.5 cm; 2- d = 0.16 cm.

Experimental results are shown in Figs. 2 and 3. It
is seen that the threshold power density for PMMA depends on the time
of irradiation as well as on the diameter of the irradiated zone, just
as in the case of inorganic solid transparent dielectric. The results
can be well explained by the fluctuation theory of dimensional effect,
which is based on the fact that during the initial stage of destruction,
thermal instability occurs around absorbing inhomogeneities. It can be
seen from the experimental data that simultaneous fixing of the place
and time of occurrence of destruction is a necessary condition for correctly
interpreting beam destruction phenomena in materials.

Morachevskiy, N. V., V. V. Morozov, and
F. S. Fayzullov. Dinamika zony lazernogo
razrusheniya v prozrachnykh dielektrikakh.
(Dynamics of the laser destruction zone in
transparent dielectrics). Moskva, 1975, 21 p.
(RZhF, 8/75, #8D1165). (Translation).

Processes of laser radiation interaction with trans-
parent dielectrics were investigated; the laser was operated in a

free-running regime. Comparative studies were made on the process of forming damage regions in silicate glass and in PMMA by a method of photographing luminescence by slit scanning and high-speed photography. Experiments were conducted on laser radiation interaction with mechanically-formed propagating cracks. It was shown that during formation of a laser damage zone, radiation interaction processes with the surface of moving cracks can play a significant role.

Kovalenko, V. S., V. P. Kotlyarov, V. P. Dyatel, V. I. Yepifanov, and K. I. Proskuryakov. Using laser beams for cutting diamond crystals. EOM, no. 5, 1975, 13-15.

Experimental methods are described for cutting or sawing and splitting of diamond crystals by laser beam, using methods developed at Kiyev Polytechnical Institute.

In laser cutting or sawing tests, the diamond crystals used were of 0.2 - 0.8 carat. Experiments were conducted with an experimental laboratory laser device as well as with a modified SLS-10-1 system. Preliminary experiments in the experimental device showed that at a radiation energy $w = 1j$, pulse duration $\tau = 0.2$ msec., focal distance $F = 13.2$ mm and pulse repetition frequency $f = 5$ Hz, it was possible to cut crystals with widths up to 0.3 carat; the time required for cutting was 2 minutes. Crystals with larger widths were cut in the SLS-10-1 device with parameters of $W = 2j$, $\tau = 0.8$ msec., $F = 16.4$ mm and $f = 0.5$ Hz. The width and depth of the gap obtained in cutting was 0.09 mm and 1.8 mm respectively, but the gap was found to be rough and covered with microcracks. The gap quality was found to increase appreciably with decrease in laser pulse duration and increase of flux density; $\tau = 0.1$ msec and $q = 10^8$ w/cm^2 gave satisfactory results, and cutting time required in this case was 5 - 10 sec.

Due to inhomogeneities present in diamond crystals, laser splitting of such crystals in a desired direction can be a difficult problem. A method is suggested here to overcome this difficulty. First, a series of low energy pulses (1 - 1.5j) are focused on the edge of crystal specimen in the desired direction; this forms a gap of 0.1 - 0.2 mm depth in the crystal, with a concentration of microcracks in its surface. Next, a few laser pulses with 8 - 10j energy are focused on the gap, which splits the crystal as required. Investigations showed that the laser method substantially reduces difficulties in preparing the preliminary gap, as well as in the actual splitting, as compared to the usual splitting method.

Buzhinskiy, I. M., and A. Ye. Pozdnyakov.
<u>Relation between the thresholds of glass des-
truction by laser pulses of different durations.</u>
KE, no. 7, 1975, 1550 - 1552.

The authors suggest an empirical formula which defines threshold densities of the average pulse power for surface destruction of optical glass as a function of pulse duration, over the range of picoseconds to milliseconds. If average threshold power density in surface destruction of glass for a pulse of duration t_1 is given by q_{t_1}, then the average threshold power density for destruction at pulse duration t_2 is $q_{t_2} = q_{t_1}(t_1/t_2)^{\cdot}$, where q_{t_1} and q_{t_2} correspond to one and the same spot diameter.

Experiments were then conducted with Nd lasers ($\lambda = 1.06 \mu$) with four different pulse durations: 1) $t_1 = 10^{-2}$ sec, smooth pulses were obtained with spherical resonator with subsequent amplification; 2) $t_2 = 10^{-3}$ sec, smooth pulses obtained as in t_1; 3) $t_3 = 4 \times 10^{-5}$ sec, smooth pulses formed using an opaque rotating shutter from 10^{-3} sec pulses and then amplified; 4) $t_4 = 4 \times 10^{-8}$ sec, single pulses obtained by Q-switching with pulses amplified to the required level. Damage threshold of glass surfaces were determined with onset of a single flare. Results of measurements were treated statistically with a stated accuracy of 20%.

t_i, sec.	q_p exp., w/cm^2		q_p calc., w/cm^2	
	K-8	GLS-1	K-8	GLS-1
$2 \cdot 10^{-11}$	—	$(1-2) \cdot 10^{10*)}$	$3 \cdot 10^{10}$	$1.7 \cdot 10^{10}$
$4 \cdot 10^{-9}$	$1.4 \cdot 10^{8}$	$0.8 \cdot 10^{9}$	$1.4 \cdot 10^{9}$	$0.9 \cdot 10^{9}$
$4 \cdot 10^{-5}$	$5 \cdot 10^{7}$	—	$4.4 \cdot 10^{7}$	$2.6 \cdot 10^{7}$
10^{-3}	$8 \cdot 10^{6}$	$4.8 \cdot 10^{6}$	$8.8 \cdot 10^{6}$	$5.1 \cdot 10^{6}$
10^{-1}	$2.5 \cdot 10^{6}$	$1.5 \cdot 10^{6}$	$2.8 \cdot 10^{6}$	$1.6 \cdot 10^{6}$

Table 1. Experimental and calculated
values of average threshold power density
for different pulse durations.

Experimental and theoretical results as calculated by
the above formula for average threshold power density in surface
destruction of type K-8 and GLS-1 optical glasses are listed in Table 1.
Results are in good agreement and verify the applicability of the suggested
formula.

Babadzhan, Ye. I., Yu. N. Lokhov, and
V. S. Mospanov. Possibility of diagnostics
of a pre-breakdown state in the surface region
of a solid transparent dielectric, according
to the spectral broadening of a high power pulse
and by change in the Brewster angle. KE,
no. 3, 1976, 563-570.

The effect is theoretically considered of energy absorption
in a transparent dielectric surface, exposed to single laser pulses of
nanosecond duration, as a function of damage to its end face. It is shown
that an electron avalanche develops much faster in a subsurface layer
of $\sim 1 \mu$ thickness than in the internal mass. Calculations are presented,
taking into account the threshold avalanche multiplication of electrons.
It is shown that a frequency shift $\Delta \omega$ due to electron avalanching, as
well as a change in Brewster angle $\Delta \varphi_B$ owing to buildup of electron
concentration in the dielectric surface layer, will occur from single-

pulse radiation passing through the dielectric. An experimental method is proposed which makes it possible to determine avalanche multiplication threshold and avalanche development constant from values of $\Delta\omega$ and $\Delta\varphi_B$.

Ol'skaya, M. A., Ye. K. Karlova, and L. A. Radushkevich. Investigating effects of the surface layer conditions of KRS-5 crystal specimens on their resistance to laser radiation interaction. In: Nauch. tr. N.-i. i proyekt. in-t redkomet. prom-sti, v. 60, 1974, 80-86. (RZhF, 5/75, #5D1242). (Translation).

Surface layer conditions of KRS-5 crystal specimens were investigated after polishing and annealing under different conditions. It was shown that polishing of specimens for laser systems should be done with polirit (not identified), and that anneal should be done in an inert gas atmosphere at a constant temperature of 200° C for one hour, and cooling at a rate of not more than 6-10 degrees/hr.

Aleshin, I. V., Ya. A. Imas, and Ye. M. Milyukov. Effect of the liquefied structure of glass on its optical breakdown threshold. OMP, no. 7, 1975, 32-33.

The effect of structural inhomogeneity of a material on its optical breakdown was modelled by way of producing microliquefied drops in laser-exposed specimens. Na_2O-B_2O_3 ($12Na_2O \cdot 88B_2O_3$) and K_2O-B_2O_3 ($10K_2O \cdot 90B_2O_3$) glass systems were selected as model liquefying materials. These glass structures were heated in a 3-liter quartz crucible in an oven at 1200-1350° C; annealing was done at 300° C. Alkali oxides were introduced in the mixtures in the form of carbonates and B_2O_3, as boric acid. Fe_2O_3 content was no more than 0.001%.

The experimental system for measuring optical break-down consisted of a laser ($\lambda = 1.06\mu$) with telescopic resonator and electrooptical Q-switch, operating in a quasicontinuous pulse mode at a duration of 10^{-5} sec. The laser beam was focused on the specimen volume by an objective at $f = 200$ mm. Formation of visible defects in the focal region served as the criterion for breakdown.

Material	Optical breakdown threshold, relative units			
	Thermal treatment duration, hours			
	0	1	3	7
No. 1 $Na_2O-B_2O_3$	1	0.59	0.52	0.47
No. 2 $K_2O-B_2O_3$	1	0.79	0.80	0.72

Table 1. Experimental results.

Results of the measurements are shown in Table 1. It can be seen that optical breakdown threshold decreases with increase in thermal treatment time. The authors point out that an increase of thermal treatment duration leads to increased dimensions of the microliquefied drops which contain the bulk of iron concentration. The iron concentration absorbs laser radiation and hence causes an earlier breakdown.

Artem'yev, V. V., A. M. Bonch-Bruyevich,
Ya. A. Imas, and V. S. Salyadinov. Absorbing
microinhomogeneities in glass and their
evolution under the action of laser radiation.
ZhTF P, no. 19, 1975, 903-907. (RZhRadiot,
4/76, #4Ye386). (Translation).

The presence of absorbing microinhomogeneities in glasses
of different composition is experimentally established, and their origin
is investigated, based on multiple action of relatively low-power pulsed
laser radiation, i.e., that does not produce visible damage. It is shown
that the "sensitivity" of inhomogeneities to irradiation increases with the
increase of absorption cross-section. Those parameters of inhomogeneities
which are significant in thermal breakdown theory, such as concentration,
absorption and scattering cross-sections, are studied. The correlation
of these parameters with threshold optical breakdown of glass is established,
which permits making use of opticostatistical methods for nondestructive
control and prediction of the optical stability of materials.

Vlasov, D. V., Yu. S. Kas'yanov, V. V. Korobkin,
and I. L. Fabelinskiy. Destruction of transparent
glass by stimulated Brillouin scattering. FTT,
no. 12, 1975, 3574-3578.

Experimental studies are described in which destruction
of transparent glass was observed as a result of stimulated Brillouin
scattering (BS) of light. The radiation source was a Q-switched Nd laser
(λ =1.06 μ), which operated in the TEM_{00} mode. Rectangular pulses of
2 nsec duration and contrast=10^4 were generated, with pulse energy of
50j and divergence =10^{-3} rad. The experimental setup is shown in Fig.
1; a brief description is outlined of the procedure. Specimens studied
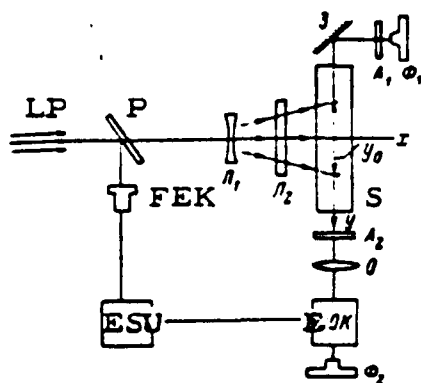were K-8 and TF-6 optical glasses as well as fused quartz.

Fig. 1. Experimental method.

LP-laser beam; P-beam splitter; L_1, L_2-cylindrical lenses; S-glass specimen; O-objective; Z-mirror; EOK-Electron-optical camera; ESU-Synchronizer for EOK scanning; A_1, A_2-filters; FEK-LED; Y-beam dimension in the focal region of the lens.

The structure of the spatial distribution of stimulated Brillouin scattering at 90° and its time evolution were closely studied. It was shown that spatial distribution of the intensity of BS light had a discrete quasiperiodic structure during each laser pulse. The character of this distribution did not change with increased laser pulse duration (up to 20 nsec) or pumping power (up to double). A study on the time kinetics of BS light distribution showed that its structure remained unchanged throughout its duration. The high contrast of BS light pulses ($\sim 10^7$), obtained at the glass specimen end faces, enabled the authors to investigate the time kinetics of self-illumination in the specimen volume in the damage region following passage of the light pulse. Measurements showed that formation of cracks and intensive illumination occur in specimens approximately 10 nsec following passage of BS pulses of 3-5 nsec duration.

Yepifanov, A. S., A. A. Manenkov, and A. M. Prokhorov. Theory of avalanche ionization in transparent dielectrics under the action of an electromagnetic field. ZhETF, V.70, no. 2, 1976, 728-737.

The problem of transparent dielectric breakdown as a result of avalanche ionization is theoretically investigated, based on approximate solution of quantum kinetic equations for electrons in the conduction zone. Diffusion equations are derived and a general expression is obtained which defines the relation between constant avalanche development and electro-magnetic field intensity. The contribution of optical phonons to avalanche breakdown is studied; values of critical fields are then determined with allowance for optical phonons.

A relationship is obtained for the critical field as a function of electromagnetic pulse duration, which is characteristic for avalanche ionization development. The range of applicability of the considered diffusion approximations is investigated, and suggestions are made for further experimental studies, which would clarify the role of the discussed mechanism in laser destruction of optical materials.

Dlugunovich, V. A., V. A. Zhdanovskiy, and V. N. Snopko. Measuring the reflectivity of dielectrics during laser heating of their surface. ZhPS, V.23, no. 6, 1975, 969-974.

Measurements of the reflection coefficients of dielectric materials including silicate glass, plexiglass, textolite, laminated bakelite insulation, ebonite, teflon and PVC were conducted during the process of their surface destruction by CO_2 laser radiation. Measurements were made using two different methods: (1) Successive measurement of the intensity

of reflected radiation at various incident angles; (2) Recording of total reflected radiation flux. Optical schemes are given for both methods in Figs. 1 and 2, and corresponding experimental procedures are described. The CO_2 laser is described only as C-IV at powers to 50 watts.
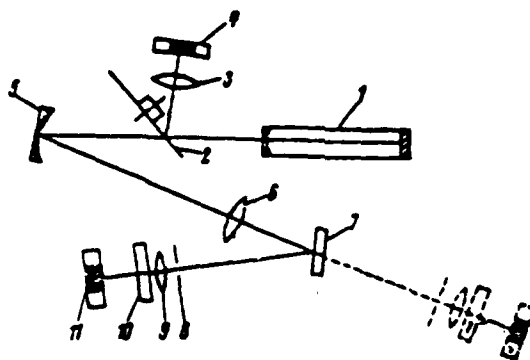

Fig. 1. Optical scheme for measuring reflection coefficient, method 1.

1-laser; 21mechanical chopper; 3,6,9-lens; 4-photoresistor; 5-mirror; 7-specimen; 8-diaphragm; 10-filter; 11-photoresistor.
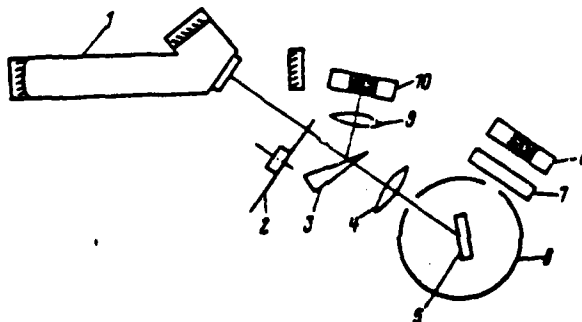

Fig. 2. Optical scheme for measuring reflection coefficient, method 2.

1-laser; 2-mechanical chopper; 3-NaCl wedge; 4,9-lens; 5-specimen; 6-integrating sphere; 7-dispersion filter; 8,10-photoresisters.

Based on their experimental results, the authors conclude that materials whose thermal destruction occurs by formation of gaseous

products, without change in their basic chemical composition, do not exhibit changes in their reflection coefficient during laser destruction of their surface. These materials include plexiglass, ebonite, PVC, teflon and silicate glass. Formation of a deep cavity during laser heating of such materials leads to an increase in effective absorption, owing to multiple reflection from the cavity walls. In the case of silicate glass, cavity edges are smooth because of the presence of a liquid phase; this eliminates multiple reflection and tends to hold the level of reflected energy constant. However, in the case of textolite and laminated bakelite, physico-chemical transformations take place during their surface heating; this leads to a considerable change in their reflection coefficient, as determined by the degree of surface heating.

Danileyko, Yu. K., A. A. Manenkov, and V. S. Nechitaylo. Pre-threshold phenomena during laser destruction of optical materials. KE, no. 2, 1976, 438-441.

A method is suggested for studying laser destruction processes, based on the observation of nonlinear optical scattering from the region of laser radiation interaction with target materials, at intensities close to damage threshold. Specimens studied in this case were sapphire crystals and type VK-104 and TF-8 glasses. Oscillograms were taken of scattered light pulses and of incident radiation at intensities close to threshold. It was observed that irreversible changes were formed within the specimens under laser radiation, even when the intensity was below threshold. This effect was cumulative in nature, giving rise to microdestruction, which ultimately led to the formation of visible macrodestruction. Explanations and interpretations are outlined of the observed effect, and its use is suggested as a test for the influence of defects on laser destruction in transparent optical materials.

Agranat, M. B., N. P. Novikov, V. P. Perminov, and P. A. Yampol'skiy. <u>Correlation of the damage threshold values of laser pulses with microstructural defects of the materials (plexiglass)</u>. MP, no. 1, 1976, 182 (Translation).

Investigations were conducted of luminescence in methylmethacrylate (MMA) and polymethylmethacrylate (PMMA) under the action of laser pulses of varying intensity ($\tau = 10^{-8}$ sec; $\lambda = 1.06\,\mu$). Subthreshold luminescence was detected in PMMA at pulse intensities up to $0.1\,I_p$ (I_p=damage threshold intensity). At $I=I_p$ luminescence power increased stepwise by 2-2.5 orders, its duration changed and its power depended on the laser pulse intensity. It is shown that I_p can be determined based on the occurrence of powerful radiation. In MMA, subthreshold luminescence was not detected during breakdown luminescence characteristics identical to those in PMMA. It was shown that I_p in MMA is 3-5 times higher than in PMMA, which explains the effect of microstructural defects in PMMA responsible for the lowering of its threshold.

In experiments with PMMA initially subjected to γ-radiation, it was noted that microstructural defects such as submicrocracks have a significant effect on the process of laser destruction; at constant I_p, the laser damage points increased with increase in γ-radiation dose. Problems are discussed on the concurrent effects of absorbing microimpurities and microstructural defects in materials.

Tribel'skiy, M. I. Optical breakdown of
transparent media with random inhomogeneities.
ZhTF P, v. 1, no. 5, 1975, 231-234. (RZhF,
8/75, #8D1164). (Translation)

Problems in the optical breakdown of transparent media
with random inhomogeneities are theoretically investigated, under
conditions of strong overlap of the temperature fields of different
inhomogeneities. Conditions for optical breakdown development, and
the correlation of its probability as a function of laser radiation intensity,
are derived for two limiting cases, namely low and high concentration of
inhomogeneities. Results are in good agreement with the work of other
authors. It is noted that the results bear a general character and depend
neither on the specific forms of the distribution of radiation intensity over
a specimen volume, nor on the heat exchange conditions at its boundary.

Leonov, R. K., G. I. Bryukhnevich, B. M.
Stepanov, N. F. Tarvin, and P. A. Yampol'skiy.
The use of a pulse electron-optical ultramicro-
scope of extreme sensitivity for study of
impurities in a transparent condensed medium.
Kvantovaya elektronika, no. 5, 1975, 946-954.

A microscopic study of absorbing metallic or dielectric
inclusions in transparent liquid and solid media is described. The
purpose of the study was to develop methods and instrumentation for
nondestructive testing for microinclusions in optical materials, spec-
ifically for high power laser use. A modified optical ultramicroscope
with a free-running pulsed ruby laser as illuminating source was used
to detect and register 10^{-4} to 10^{-6} cm size inclusions in $10^{12}/cm^{-3}$
concentrations in optical materials having a very high breakdown
energy threshold.

A variant of the ultramicroscope technique, incorporating a five stage image intensifier with electromagnetic focusing and a camera, was used for noise-free recording of images of a single scattered photoelectron. This latter modification is particularly suitable for recording of inclusions with the cited dimensions at optical power densities exceeding breakdown threshold. The authors believe that new valuable data on microstructure of optical materials can be obtained, and strongly-absorbing inclusions can be identified and nondestructively recorded, by using the refined method described.

3. Semiconductor Targets

Obukhov, L. V., Ye. G. Prutskov, and V. A. Yanushkevich. <u>Microstructure and motion of dislocations in laser irradiated silicon.</u> FiKhOM, no. 2, 1975, 34-38.

An experimental study on crater and dislocation formation in laser-exposed Si specimens is briefly described. Emphasis is on microstructure effects as functions of laser energy and temperature, for which data is claimed to be generally lacking in the literature. A free-running ruby laser was used on Si single-crystal wafers oriented in the [111] direction, and heated at various temperatures up to $950^{\circ}C$. Pulse energies were in the range of a fraction of a joule up to about 1 joule, at densities in the $10^5 - 10^6$ w/cm^2 range.

Following exposure, specimens were etched and observed by microscope. The relations of dislocation path length to pulse energy and duration are obtained. Results show that dislocations propagate at rates on the order of several meters per second. Typical dislocation patterns around the laser crater are shown. The patterns are classified according to the relation between crater diameter and dislocation path length. A sample photo of irradiated p-Si is included.

Gomonova, A. I., and Yu. V. Ponomarev. <u>Restoration of a P-I-N photodiode after irradiation by powerful light pulses.</u> VMU, no. 1, 1976, 32-38.

Photodiodes with P-I-N structures, when irradiated by sufficiently intense light pulses, lose their sensitivity to weak signals. It therefore becomes necessary to determine the time required for recovering the sensitivity lost from such exposure. This time interval is related to the

restoration of carriers, accumulated in the central lightly-doped P-I-N region of the photodiodes. The present work discusses the resorption process of moving charge carriers thus accumulated in the I region of the diode.

At high incident light intensities, a quasineutral region with a large number of excess moving charge carriers is formed inside the I region. The dimensions of this quasineutral region increase with intensity of incident light. Following illumination, the accumulated charge begins to resorb as a result of recombination as well as from flow through the boundaries of this region. It is assumed that the restoration process in photodiodes takes place at constant negative currents. The restoration problem is treated here as two stages: first a decrease of charge concentration at the boundary of the quasineutral region, followed by a further restoration process which begins at the moment when concentration at the quasineutral region boundary decreases to an equilibrium state. The results obtained enable one to evaluate duration of the carrier resorption process at different exposure intensities.

Kachurin, G. A., N. B. Pridachin, and L. S. Smirnov. Annealing radiation defects by pulsed laser radiation. FTP, no. 7, 1975, 1428-1429.

The action of short laser pulses on properties of Si and GaAs, alloyed by implantation of phosphorus and tellurium ions respectively, was investigated. Specimen dimensions were 10x5x0.5 mm. Irradiation was done at room temperature by a Q-switched ruby laser in a single pulse regime. Pulse energy was 0.1 joule at a duration of 30 nsec. The beam was focused on the specimen surface to a spot of 15 mm diameter. A transparent 0.1 μ protective film of Si was deposited on the surface in the case of GaAs, so that possible evaporation of arsenic was precluded.

It was observed that a single laser pulse was ample for annealing defects in the implanted layers and obtaining a high concentration of free electrons. Measurements of electric conductivity and Hall effect along with precision laminar etching showed that volume concentration of carriers in phosphorus alloyed Si was 1.5×10^{20} cm^{-3} and in Te-alloyed GaAs, 10^{18} cm^{-3}. Carrier mobility in GaAs after a single laser pulse was 1000 cm^2/v·sec, even in cases when ion bombardment led to amorphization of alloyed layers (irradiation at 20° C), which indicated recrystallization of the layers. Carrier mobility in case of Si was lower than calculations.

Based on an earlier published method, the temperature rise of the surface layer due to a single laser pulse was calculated for GaAs. This showed that the surface temperature did not rise more than 150° C. Thus the obtained results demonstrate the possibility of low-temperature anneal of ion-implanted layers by pulsed laser radiation, and show that the process of annealing takes place at a very fast rate leading to structural recrystallization and to electrical activation of implanted admixtures.

Kostyukova, Ye. P., L. I. Mirkin, and K. N. Nishchev. X-ray topographic study of structural changes in silicon single crystals under the action of a laser beam. FTT, no. 9, 1975, 2635-2639.

Structural changes in silicon single crystals exposed to laser pulses were investigated by x-ray topographic methods of Schulz, Berg-Barrett and wide divergent beam (pseudo-Kossel). Si single crystals of cylindrical shape with height of 3 mm and diameter of 25 mm were irradiated on the <111> surface by laser beams with pulse energy of 30 j and duration = 10^{-3} sec; energy density was varied by beam defocusing. For studying distribution of

structural distortions at different distances from the beam impact spot a method was developed for taking photographs at various settings of crystal specimens relative to the x-ray source.

X-ray topography and optical investigations showed that the action of the laser beam on the <111> surface caused the formation of a thin distorted layer, the orientation of which was similar to the main crystal. The thickness of this layer depended on the specific level of surface irradiation; in the case of a diverging beam this amounted to less than 30 μ. Partial relaxation of internal stresses was observed in the layer thus formed, which gave rise to destructions along the <110> plane, and as a result the layer split into several rhombic portions. Dimension of the rhombic portions in the present experiment was 70 μ and they were found to lie at an angle of 2° relative to each other, showing a high level of internal stress. Beneath the distorted layer, the crystal specimen was found to be unaffected.

The authors note that investigation of deformation and mechanical destruction from the action of a laser beam on crystals accounts only for destructions on the cleavage plane of the specimen, whereas the x-ray topographic methods enable one to show the preservation of surface layer orientations during crystal destruction. Several diffraction photos are included in the paper.

Nguen Min' Khiyen. Nonstationary theory of thermal breakdown of semiconductors under laser radiation. ZhTF, no. 10, 1975, 2105-2108.

Nonstationary processes during the development of thermal breakdown in semiconductors under the action of laser radiation are theoretically investigated. The problem is treated with the assumption that heat exchange between the crystal and surrounding medium occurs by free convection. Scattering and attenuation of light during its passage through the crystal are neglected. Two cases are considered: a) semiconductor

specimens in the form of an unbounded plane plate of thickness 2H; and b) cylindrical specimens with radius R and length L, where $L \gg R$.

For both geometries expressions are derived for determining the onset of temperature instability and ensuing breakdown. From the results obtained, final expressions are derived for the threshold intensity q_{th} and breakdown development time τ_{ind}. In an example given, q_{th} and τ_{ind} for a Ge plate are calculated to be $q_{th} = 1 \text{ kw/cm}^2$ and $\tau_{ind} = 10$ sec.

Tovstyuk, K. D., G. V. Plyatsko, Ye. S. Nikonyuk, S. G. Kiyak, and Ya. V. Bobitskiy. Characteristics of powerful laser interaction with cadmium telluride single crystals, doped with bromine and germanium. UFZh, no. 4, 1976, 689-691.

The possibility of changing conductivity type was studied in n- CdTe:Br and CdTe:Ge single crystals, by fusing their surface layer with powerful laser radiation at $\lambda = 1.06 \mu$ and $\lambda = 0.694 \mu$. CdTe:Br specimens had a carrier concentration of $5 \times 10^{17} \text{cm}^{-3}$ and CdTe:Ge, 10^{15}cm^{-3}. Their p-n-junctions were studied in laboratory conditions under exposure to ruby and Nd lasers. Laser irradiation of these semiconductors led to strong absorption by their surface layer resulting in their fusion. The rate of surface layer heating by laser pulses of 2-9 msec duration was more than 10^5 deg/sec. The corresponding fast cooling rate, 10^3-10^4 deg/sec, led to recrystallization and formation of sharp gradient of mixtures in the base and recrystallized regions of the specimen. It was observed that the conductivity of these fused and recrystallized layers of CdTe:Br and CdTe:Ge was changed to p-type. In addition, p-n junctions were found to form at the phase interface of the recrystallization region. Oscillograms

were taken of both dark and exposed V-A characteristics of the junctions thus formed, and their photoelectric characteristics were measured. The V-A characteristics showed that diodes generated in this manner by laser irradiation exhibit sharp and stable p-n junction which are transparent to tunneling effects.

In conclusion, the authors note that the suggested method provides p-n junctions of large surface area lying at different depths. This method is seen as superior to the usual diffusion technique, where the main disadvantage is the erosion of p-n junctions and consequent aging of devices based on them.

Tovstyuk, K. D., G. V. Plyatsko, V. B. Orletskiy, S. G. Kiyak, and Ya. V. Bobitskiy. Characteristics of powerful laser interaction with $Pb_{0.83}Sn_{0.17}Te$ solid solution. UFZh, no. 4, 1976, 531-534.

The experiment of the preceding article was also performed by the same authors on $Pb_{1-x}Sn_xTe$ single crystals. Specimens used in the present experiment were n-$Pb_{0.83}Sn_{0.17}Te$, with carrier concentration at 77 K equal to $4x10^{16}$ cm^{-3}. The experimental sketch is shown in Fig. 1.
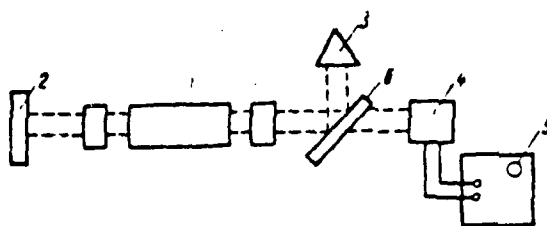

Fig. 1. Experimental sketch.

1- laser; 2- target crystal; 3- IKT-1m for measuring radiation power; 4- photoelement; 5- oscillograph; 6- splitter.

Irradiation was again by ruby ($\lambda = 0.694 \mu$) and neodymium ($\lambda = 1.06 \mu$) lasers in a free-running mode, generating near-rectangular pulses of 2 to 9 millisec. Q-switching was done by a solution of organic dyes in nitrobenzene; pulse power in this regime was 3 Mw with a duration of 20 nsec. Threshold power density for fusion and recrystallization of the surface layer of an exposed single crystal in the case of an Nd laser equalled $E = 0.15 \, j/mm^2$ at pulse duration $t = 2$ msec. Thickness of the fused layer increased with the increase of radiation energy density and it equalled 0.1 mm at $E = 0.5 \, j/mm^2$ and $t = 7$ msec. It was detected that n-type conductivity of the studied $Pb_{0.83}Sn_{0.17}Te$ specimen, when irradiated, changed to p-type after fusion and recrystallization. Other findings generally parallel those of the authors' foregoing paper.

Agasiyev, A. A., A. Kh. Zeynally, V. M. Salmanov, V. I. Tarirov, and K. Yu. Karakurkchi.
Obtaining crystallic films of sulfoiodide, antimony sulfide and indium selenide under pulsed sublimation by laser. FTP, no. 6, 1975, 1170-1172.

Techniques for obtaining films of complex ferroelectric semiconductors, namely SbSI, Sb_2S_3, InSe were investigated using a Q-switched ruby laser for vaporization. Flux density on the above target surfaces was about $10^9 \, w/cm^2$. Films were deposited in vacuum at 10^{-4} torr on isotropic substrates of glass and smooth quartz as well as on NaCl single crystals and mica sheets (muscovite). Substrates were placed at 20 mm from the target and their temperature was varied from 50 to 300 C. Film thicknesses of several hundred angstroms were obtained during a single laser pulse in the case of SbSI and SbI_3, while in the case of Sb_2S_3 and InSe, several pulses were required to obtain the same thickness. Film structures were studied by means of an electron diffraction camera (Fig. 1). Calculations based on electron diffraction patterns showed good
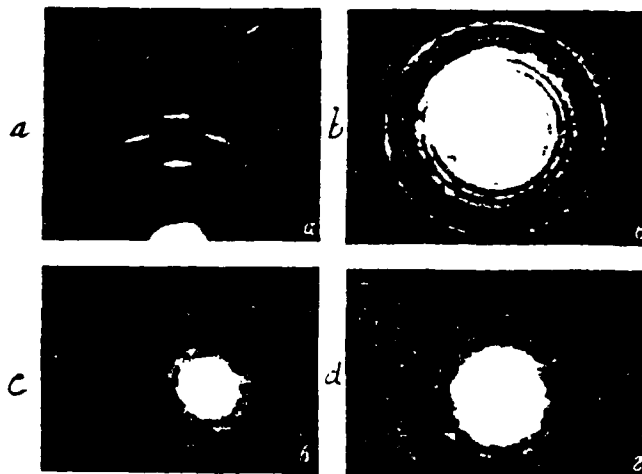
Fig. 1. Electron diffraction pattern of films
deposited on NaCl at different temperatures:

a) SbSI at 150 C; b) SbI$_3$ at 100 C; c) Sb$_2$S$_3$ at
230 C; d) InSe at 300 C.

agreements between parameters of deposited films and of the initial
substance, except for the fact that the epitaxy temperature in the case
of laser excitation was little lower than for deposition by thermal
vaporization.

Antonenko, A. Kh., N. N. Gerasimenko, A. V.
Dvurechenskiy, L. S. Smirnov, and G. M.
Tseytlin. Distribution of implanted impurities
in silicon after laser annealing. FTP, no. 1,
1976, 139-140.

The present work investigates dissociation of defects and
activation of impurities during laser annealing of semiconductors.
Distribution of active impurities and residual defects are experimentally
studied.

Experiments were conducted with p-Si specimens having ρ = 10 and 2000 ohm x cm. P^+ ions were implanted at energies E = 30 and 100 Kev, and doses up to 6.25 x 10^{14} and 1.6 x 10^{16} cm^{-2}, respectively. Pulsed radiation sources were a Q-switched Nd laser (λ = 1.06 μ, τ = 10-30 nsec, radiation power up to 4 x 10^7 w/cm^2) and a ruby laser with τ = 3 msec and P = 10^5 w/cm^2). Charge carrier profiles were recorded by EPR signal measurements of electron conductivity at 77°K; phosphorus atom distribution was obtained by a neutron-activation method. Experimental results are shown in Figs. 1 and 2.
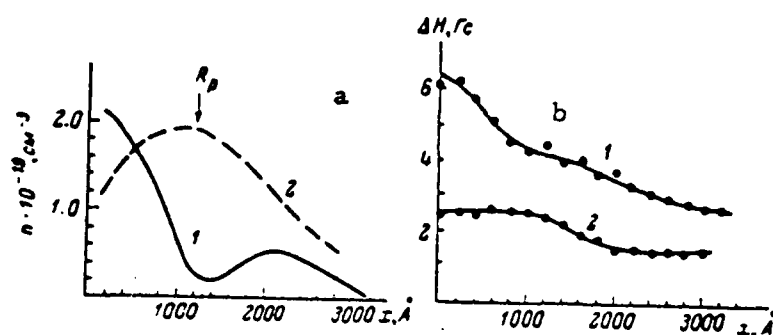

Fig. 1. Change in free electron concentration (a) and width of EPR signal lines (b) with depth of Si specimens, irradiated by P^+ ions with E = 100 kev, dose D = 6.25 x 10^{14} cm^{-2}. 1- laser anneal, 2- thermal anneal.
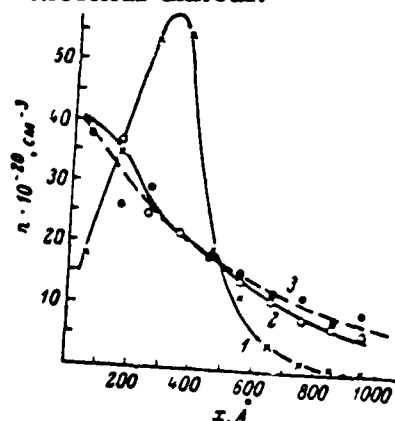

Fig. 2. Phosphorus atom distribution profile in Si specimens, irradiated by P^+ ions with E = 30 kev, D = 1.6 x 10^{16} cm^{-2}. 1- Before laser irradiation; 2- after Nd laser irradiation; 3- after ruby laser irradiation.

The tests show that fading of EPR signals of vv-centers and the appearance of lines in the EPR spectrum as a result of electron conductivity begin at a specific threshold power W_{th}, e. g. $W_{th} = 2 \times 10^7$ w/cm^2 for the Nd laser. Electronographic studies showed that when $W > W_{th}$, an amorphous layer changes to a monocrystalline state.

As a result of laser anneal of specimens, maxima of electron conductivity (Fig. 1a) and P-atom profile (Fig. 2) shift towards the surface with respect to calculated penetration R_p of P$^+$ ions. Also a spreading of the profile was noted after laser anneal (Fig. 2). Thermal anneal of similar specimens in inert gas at 1000° C gave a distribution of charge carriers similar to calculated values of R_p (Fig. 1a).

The character of changes in EPR signals and electron conductivity (Fig. 1b) show an increased concentration of defects on the surface following laser anneal. In thermal annealing, these defects are seen in the R_p region, but their concentration is low.

The authors conclude that at least two mechanisms could account for the observed effects, namely segregation of impurities, and diffusion of impurities, which are discussed.

Blynskiy, V. I. Laser doping of silicon in a free-running regime. Kvant. fiz. elektronika. Minsk, 1975, 85-86. (RZhF, 18Ye, 1/76, #1Ye994). (Translation)

Possibilities were investigated of n-type (15 ohm x cm) and p-type (0. 5 ohm x cm) Si doping under the action of Nd laser pulses on Al, In and B$_2$O$_3$ films placed on the crystal surface. Heating temperature did not exceed 2600 C; fusion zone diameter was 60-100 μ. It was found that the force of optical pressure on the films exceeded forces of surface tension, gravity and reactive pressure of the evaporating material by 4

orders. During doping of aluminum, sharp p-n junctions were observed with a p-region width 0.2-0.6 times the radius of the fusion zone. It was concluded that Al films are imbedded in the fusion region owing to optical pressure and intermix with the Si; the fusion region then crystallizes during fast cooling, forming alloy junctions. Doping of Si with In and B_2O_3 films led to negative results; this was possibly due to low melting point and bad adhesion of In, and to the lack of thermal decomposition of B_2O_3.

Bolotov, V. V., N. B. Pridachin, and L. S. Smirnov. Laser annealing of defects responsible for secondary optical absorption in ion-irradiated GaAs. FTP, no. 3, 1976, 566-567.

Tests are briefly described on laser annealing of transparency fluctuations, which occur from disorders produced by ion bombardment of gallium arsenide. Optical transmission of semi-isolated GaAs in the 2-25 μ region was measured after its bombardment by hard tellurium ions. Measurements were done with a dual-beam spectrometer at room temperature. Te ion bombardment was done at 40 kev energy a current density of 0.5 μa/cm^2 and dose of 10^{15} cm^{-2}. Laser anneal was done with a pulsed ruby laser with pulse duration of 30 nsec and ~ 0.1 j energy. Focal spot area was 0.5 cm^2; the beam was defocused by a diverging lens.

Experimental results were as follows. Initially, the GaAs specimen had an absorption coefficient α = 0.3-0.5 cm^{-1} in the 2-5 μ spectral region. Irradiation by Te ions caused a sharp increase of α = 5x10^3 cm^{-1}. Annealing of the specimen with the ruby laser caused complete restoration of the lost transparency, and the absorption coefficient decreased back to its initial value.

Experimental results show that pulsed laser annealing is very efficient for eliminating attenuations in transparency, resulting from ion bombardment, and possibly could be adapted for optical data storage.

Fedorenko, L. L., V. K. Malyutenko, and S. S. Bolgov. Activation of photoconductivity in InSb by laser radiation. UFZh, no. 12, 1975, 2040-2043.

Results are described of the interaction of laser radiation with InSb semiconductors, at energy levels generally insufficient for causing structural damage. Crystal plates of n- and p-InSb with dimensions of 1 x 3 x 0.05 mm were irradiated by Q-switched ruby laser pulses of 5×10^{-8} sec. and 0.1 j energy. The diameter of the light spot was made larger then specimen dimensions, with flux density being regulated by neutral filters. Before laser exposure the target face was etched in a standard etchant. Experiments were conducted in a cryostat at T = 200 K in vacuum not less than 10^{-3} torr. Studies were made of stationary photoconductivity and its kinetics, V-A characteristics, and the photoconductivity of crystals in crossed electric and magnetic fields.

It was found that multiple irradiation of an InSb specimen surface by ruby laser pulses caused an increase of stationary photocurrent amplitude and an increase in decay time of photoconductivity signals in the specimen. This improvement of photoconductivity parameters ceased in the present experiments after 10-15 shots of surface irradiation, at pulse densities not over 10^6 w/cm^2. Further irradiation caused degradation of photoelectric and optical properties, which is apparently a function of mechanical surface damage.

66

Typical oscillograms of the photoconductivity of n-InSb crystals are shown in Fig. 1. Since the absorption coefficient of laser
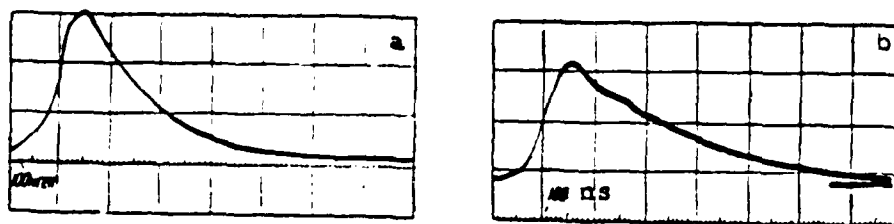

Fig. 1. Kinetics of photoconductivity of n -InSb before (a) and after (b) activation by laser pulses. E = 60 v/cm; H = 10^3 oe.

radiation at 0.69 μ in InSb is more than 10^4cm^{-1}, and surface damage from laser exposure as was absent, the authors conclude that the increase in photoresponse time and stationary photocurrent is related to a decrease in surface recombination rate in the irradiated crystal face. This assumption is supported by V-A characteristics taken of dark- and photo-currents in rossed fields. From calculations, surface recombination rates in InSb crystals before and after laser exposure were found to be 2.8 x 10^3 and 6.3 x 10^2 cm/sec respectively.

Ivlev, G. D., and A. Ya. Peshko. Comparing conditions of p-n junction formation by means of ruby and Nd lasers. IN: Sb. Kvant. fiz. elektronika. Minsk, 1975, 83-84. (RZhRadiot, 1/76, #1Ye498). (Translation)

Conditions for formation and the electrical characteristics of p-n junctions based on gallium arsenide are compared, obtained by means of ruby and Nd lasers. The initial semiconductor material used was n-type tellurium-doped gallium arsenide carrier concentration = 10^{17} cm^{-3}). The V-A characteristics of p-n junctions were investigated, formed by radiation flux densities on the specimen surface in the range of

67

$10\text{-}40 \ j/cm^2$ and $40\text{-}150 \ j/cm^2$ with ruby and Nd lasers, respectively.

Dogadov, V. V., B. A. Raykhman, and V. N.
Smirnov. Variations in transmission near the
absorption edge of doped gallium arsenide under
the action of radiation pulses at $\lambda = 10.6 \ \mu$.
ZhTF P, v. 1, no. 5, 1975, 251-255. (RZhF,
8/75, #8D1160). (Translation)

Variations in transmission near the absorption edge of
p-type GaAs ($p = 10^{18} cm^{-3}$) were investigated, the changes being induced
by heating specimens with laser pulses at $\lambda = 10.6 \ \mu$. Laser radiation
is strongly absorbed by the considered material, at an absorption coefficient =
$30 \ cm^{-1}$. The intensity of CO_2 laser radiation at the lens focus attained
$20 \ Mw/cm^2$. The probing radiation spectrum was in the range of 1.30-
1.35 ev. The relative change in transmission was up to 50%. Quantitative
interpretations are given of the results, based on conditions under which
the probe radiation propagates in media with inhomogeneous induced
absorption.

Myl'nikov, V. S., A. A. Kharchenko, and M. M.
Sobolev. Photoinduced conductivity and threshold
destruction of copper organoacetylenides under
Nd laser radiation. KE, no. 2, 1976, 288-292.

A study is reported on Nd-laser induced photoconductivity and
damage thresholds of metalloorganic semiconductors - copper
organoacetylenides of the type $CuC \equiv C$-R, where R is butyl, phenyl or
anthracyl. An attempt is made to explain the role of primary photoelectric
processes in the laser destruction of these compounds, as well as the
relation between forbidden band width and threshold level. The experimental

68

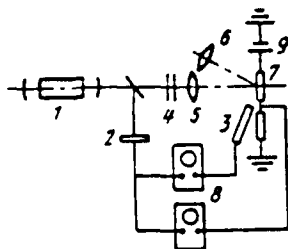diagram is shown in Fig. 1. The Nd laser was operated at 1.06 μ both

Fig. 1. Test system for determining damage
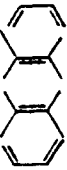threshold and recording photoconductivity.

1- Nd laser; 2- photoelement; 3- photomultiplier;
4- neutral filters; 5- lens; 6- microscope;
7- specimen; 8- oscillograph; 9- voltage source.

free-running and with giant pulses, at pulse durations of 10^{-3} and 3×10^{-8}
sec respectively; their corresponding upper intensity limits were 10^{25} and
5×10^{26} photon/cm^2 x sec respectively. Radiation was focused on specimens
in both regimes by a lens with f = 10 cm; focal spot diameter in the free-
running regime was 2 mm and in giant pulse regime 0.1 mm.

Damage threshold was determined as the average level
causing flare generation, based on a series of ten flares for different
specimens, as well as for different points on the same specimen; maximum
deviation of threshold from the mean was 20%. Photoconductivity
was recorded using a preamplifier with input impedance of 3×10^6 ohm and
bandpass up to 1 MHz, and displayed by oscillograph. The relationship
of photocurrents as a function of intensity was recorded by neutral filters;
measurements were conducted in air.

The main energetic characteristics of the target materials are
given in Table 1. The relation between damage threshold and forbidden
gap width is shown in Fig. 2. It can be seen that in either lasing mode,
damage threshold of copper organoacetylenides increases continuously
with increase in forbidden gap width in the 1.9-2.7 ev range. Relationships

69

Table 1. Energetic characteristics and threshold destruction of copper organoactylenides.

№№	Combination	φ, eV	ΔE, eV	$P_1, \frac{kw}{cm^2}$	$P_2, \frac{kw}{cm^2}$
I	$CuC \equiv C - C_6H_9$	5,25	2,73	51	2
II	$CuC \equiv C -$ ⬡	5,24	2,39	47	1,9
III	$CuC \equiv C -$ (anthracene structure)	5,03	2,14	37	1,4
IV	$Cu_2C_2 + CuC \equiv C -$ ⬡	—	1,9	16	0,5

φ - Photoelectric work function.
Δ - Forbidden gap width.
P_1 - Threshold with free-running generation.
P_2 - Threshold with giant pulses.
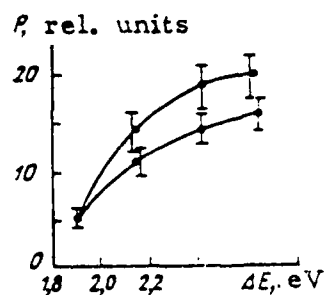
Fig. 2. Damage threshold of copper organoacetylenides as a function of forbidden gap width in free-running (lower curve) and giant pulse regimes (upper curve).

are similar in both cases, which suggests a similar damage mechanism in both regimes. In the case of copper phenylacetylenides, presence of impurity conductivity, photoinduced by laser radiation, was also detected, which starts at energies three orders of magnitude below the damage threshold.

4. Miscellaneous Studies

Samarin, A. V., B. M. Klimenko, R. Ye. Liberzon
and B. P. Rumyantsev. Investigating the temperature
field of a supported panel under pulsed heating. I-FZh,
v. 29, no. 1, 1975, 116-119.

The temperature field of a panel, coupled with supporting
elements, such as longerons, bulkhead frames, etc., exposed to pulsed
heat fluxes is discussed. Contact thermal resistance between the panel
and support elements is neglected; the size of the contact area is assumed
small compared to panel dimensions, so that the problem of determining
the temperature field of such a panel reduces to the problem of heating a
rod of length l with a concentrated mass m at one end (Fig. 1). Solutions
are obtained in the form of series, which converge rapidly at small and
large values of time.

Sample calculations are given for a steel plate, and results
are plotted in Fig. 2. Experiments were conducted with an IR heating device,
equipped with a quartz lamp heater, which applied thermal flux up to 700
kw/m^2 on the target specimen. The specimen used was a steel plate
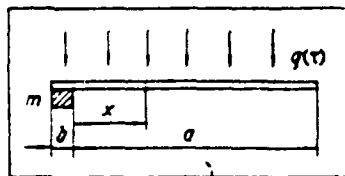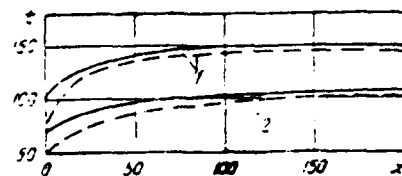

Fig. 1. Model of panel heating.

Fig. 2. Temperature field of the panel.
Solid curve - calculations. Dashed curve -
experiments. (1) $\tau = 3$ sec; (2) $\tau = 1$ sec.
(t in °C; x in mm).

600 x 600 x 1 mm thick. Pulsed exposure of the specimen was done by means
of a high-speed shutter. Calculated and experimental fields are seen to be
in close agreement.

Lyubov, B. Ya., and E. N. Sobol'. <u>Nonstationary</u>
<u>evaporation of a semiconfined body under the action</u>
<u>of strong energy flux.</u> FiKhOM, no. 5, 1975, 3-8.

The problem of nonstationary evaporation of a semiconfined
body is discussed in the region of a moving phase boundary, taking into
account the exponential relationship of evaporation rate as a function of
surface temperature T_s for arbitrary initial conditions. The method used
allows for the effect of initial temperature distribution on the kinetics of
evaporation, which is important for analyzing temperature stresses in
materials, resulting from laser exposure. The temperature dependence of
thermophysical and reflection coefficients, and the process of material fusion
are in this case neglected.

Based on the one-dimensional problem of evaporation of a
semiconfined body under constant energy flux, the authors obtain the
temperature field and rate of evaporating surface displacement in the form
of exponential series for small time increments; these series do not give
a stationary solution. The duration of nonstationary processes is determined
by considering evaporation stages, approaching the stationary regime.
Sample calculations are given of nonstationary periods for Aℓ and Cu,
assuming an incident flux density of 100 Mw/cm^2.

Smirnov, V. N. <u>Action of optical radiation on a</u>
<u>circular plate.</u> ZhTF, no. 12, 1975, 2479-2484.

The action of optical radiation on thin circular plates, leading
to heating and hence thermal stresses in the latter, has been studied in
several previous works. However, according to the author, the possibility
of minimizing thermal stresses by changing boundary conditions on the plate
contour has not been adequately studied. The present work considers the
action of pulsed and steady-state optical flux, with a Gaussian distribution
of power density on the surface of a circular plate.

Results show that the type of boundary conditions in the exposed contour significantly affect the values of temperature and induced thermal stresses. Boundary conditions are theoretically determined which would result in minimal stress from laser exposure. An example is given showing that up to a six-fold difference in thermal strength can exist for a given flux density, depending on surface heat exchange conditions.

Gorshkov, B. G., Yu. K. Danileyko, A. S. Yepifanov, V. A. Lobachev, and A. A. Manenkov. Laser destruction mechanism of alkali-halide crystals: Investigating the temperature dependence of breakdown threshold. ZhTF P, v. 2, no. 6, 1975, 284-287.

A study is described on the temperature dependence of the damage threshold of alkali-halide crystals. The test was intended to determine whether electron avalanching produced by shock waves is the main mechanism for material destruction. Crystal specimens studied were NaCℓ, KBr, NaF, LiF; both ruby and Nd lasers were used for irradiation.

Experimental relationships of damage threshold are shown in Figs. 1 and 2. Analysis of the results shows that a 'pure' electron avalanche, i. e. an avalanche developing in an ideal crystalline structure, cannot be taken as the dominant mechanism of laser destruction. It is possible that impurities and defects play a significant part, either radically changing the picture of avalanche ionization or acting as the main mechanism for thermal destruction. The authors conclude that it may be necessary to conduct special investigations on the role of electron spatial diffusion in the destruction of transparent dielectrics.
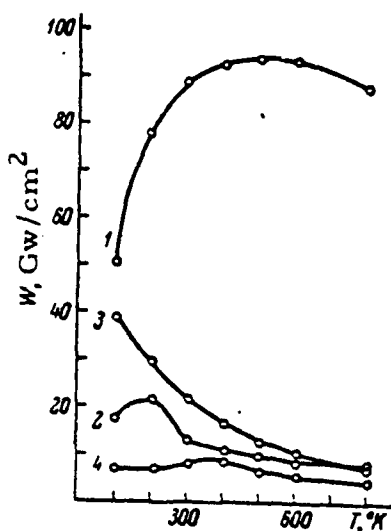
(Fig. 1 and 2, see next page)

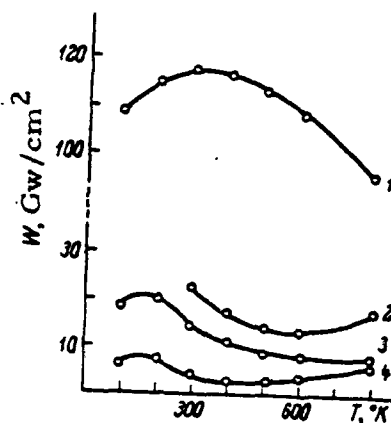Fig. 1. Threshold intensity W as a function of temperature T; ruby laser.

Fig. 2. Temperature dependence of damage threshold, Nd laser.

For both figures, 1 - NaCℓ-I (η = 1-8);
2 - NaCℓ-II (η = 5-11); 3 - NaCℓ-III ($\eta \sim$ 100);
4 - KBr (η = 8-70).

Mukhamedgaliyeva, A. F., A. M. Bondar', and T. A. Ziborova. Effect of IR absorption spectrum deformation in microcline (KAℓSi$_3$O$_8$) caused by CO$_2$ laser radiation. ZhTF, no. 4, 1976, 873-874.

The effect of focused c-w CO$_2$ laser radiation at a power density of 0.5×10^5 w/cm^2 was studied on microcline specimens (KAℓSi$_3$O$_8$), which is one of the most widely distributed metal groups (about 50%) over the earth's surface in the form of feldspar. Laser irradiation on microcline led to intensive heating of the specimen with formation of fusion in the focus region and generation of a luminous flare after a period of 1-2 sec. The temperature of the flare was about 2000 C. After 30 seconds of exposure a hole was formed, which was coated with glassy colorless transparent mass. Under the glassy melt a dull-white crystalline zone of 0. -1. 5 mm thickness was noted. Further below, a dark zone of thickness up to 5 mm was found, below which the microcline retained a red-orange color through-

74

out. The laser interaction processes were also studied by means of IR absorption spectra, as shown in Fig. 1.
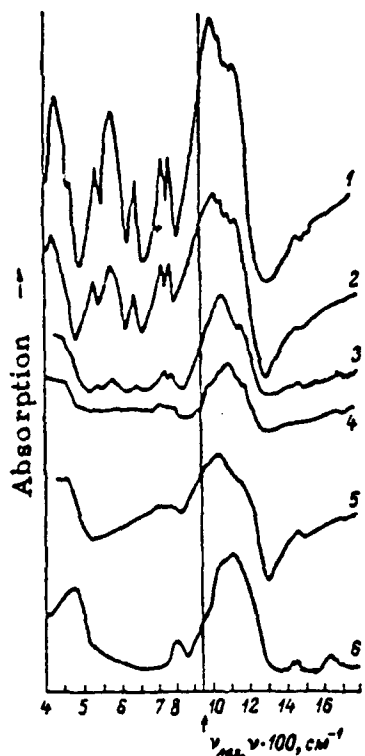
Fig. 1. IR absorption spectra of microcline
(1, 2, 3, 4) and spectra of thermal fusion (5)
and laser sublimation products of microcline (6).

Analyses of the obtained results show that the observed changes of microcline products as a result of laser irradiation occurred not because of the usual structural reordering in the process of simple thermal heating and fusion, but because of specific laser effects in 'burning out' spectral lines. This effect is associated with the onset of phase transformation and structural reordering by powerful monochromatic laser radiation, which is not characteristic for the usual thermodynamic stable solid phase and fusion at high

temperatures. In the case considered, dissociation takes place of Si-O bonds, together with sublimation of radical silica complexes (Si_mO_n).

Kozlov, B. M., A. A. Samokhin, and A. B. Uspenskiy. Numerical analysis of pulsating evaporation of a condensed material under laser radiation. KE, no. 9, 1975, 2061-2063.

In laser-target interaction a pulsating mode of evaporation occurs as a result not only of strong absorption in plasma or vapor in front of the irradiated surface of a condensed material, but also because of periodic explosive decay of overheated metastable layers of liquid phase in the irradiation region. Such pulsations were observed experimentally, for example, in the work of Karlov, et al. (ZhETF P, 19, 1974, 111) during the action of CO_2 laser radiation with density $I = 6 \times 10^3$ w/cm^2 on the surface of absorbing liquids (acetone, ethanol).

The present work investigates and presents a numerical analysis of the effect of unstable temperature profile on the period of such pulsations, based on a model with constant thermophysical parameters. The authors show that when the maximum of temperature profile reaches a limit overheating value, explosive decay takes place of the metastable phase in the localized region of this maximum. This causes ejection of the liquid surface layer, thereby forming a new boundary layer, i.e. a new evaporation front. The process repeats itself to form a regular pulsating mode of the evaporation. Numerical solutions of the corresponding boundary-value problem for heat flow equations in a moving boundary region show that the process of steady-state periodic pulsations is nonmonotonic, with the shortest duration falling in the interval between the first and second explosion after the initiation of radiation. At a density of 2×10^3 w/cm^2, the times of occurrence of the first four explosions were $\tau = 0.134$, 0.16, 0.198, and 0.24 [sic]; the period between the first and second explosions is the smallest.

The authors point out that the character of the pulsating evaporation mode is very sensitive to the values of thermophysical parameters, therefore it could be used for experimental determination of the behavior of these parameters in a metastable region.

Geguzin, Ya. Ye., A. K. Yemets, and B. G. Kononenko. <u>Dislocation mechanism of macroscopic cavity formation at the focus of pulsed laser interaction in crystals.</u> FTT, no. 10, 1975, 2984-2988.

Cavity formation in single crystals was investigated under the action of pulsed laser radiation. The experiment was conducted with a ruby laser, operating free-running with pulse duration $\tau = 10^{-3}$ sec. and energy up to 20j. The target specimen was KCℓ single crystal with dislocation density $\rho = 5 \times 10^5$ cm^{-2}, grown from solution. Radiation was focused in the specimen volume (1 x 1 x 2 cm) with a lens of f = 10 cm.

At sufficiently high flux density, destruction was generated within the specimen in the form of axisymmetric cavities, extending along the beam and surrounded by cracks. Damage regions were studied under microscope in polarized and natural light. Polarized optical observations showed that stresses are present in regions adjacent to cavity formation. A microphotograph of a damage zone in linearly-polarized light is shown in Fig. 1, where bright rays are seen extending out in the <100> direction. It is shown that rays extending in the <110> direction are regions of compression, and that tension regions lie on either side of these. Lengths of the compression rays increase with increase in cavity size. The relation between the length of compression rays X^o and size of cavity R is shown in Fig. 2. A theoretical model of the observed mechanism is described in detail, which along with experimental results enables determination of the parameters of the process.

Fig. 1. Polarized pattern of stresses in KC𝑙 crystal near cavity formation. Rays going out from the pore center are compression; white regions bordering them are tension.
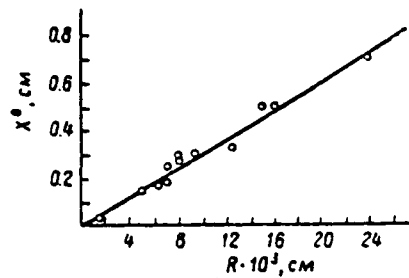
Fig. 2. Ray length of polarized stress pattern X^O, as a function of cavity radius R.

Volkov, S. A. Pulsed discharge in vapors, formed during evaporation of metallic aerosol by laser radiation. IN: Tr. Leningr. in-ta tochnoy mekh. i optiki, no. 79, 1975, 46-49. (RZhRadiot, 6/75, #6Ye272). (Translation)

The possibility of exciting a volume electric discharge is experimentally verified in vapors, formed during thermal action of laser radiation on a dispersed gas medium. According to the suggested scheme, particles of powdered metallic lead were suspended in the field of a plane condenser, operating in a delayed switching mode; the particles were then irradiated by a neodymium laser. Intensive particle evaporation and discharge of the 0.1μF condenser in the resulting plasma were observed during laser irradiation of the interelectrode gap. At voltages up to 40 kv on the condenser C, a uniform discharge was noted all over the gap without formation of any sparks. The duration of pulsed current in this case was 0.5 - 5 μsec, depending on the condenser voltage and particle concentration of the powder.

A uniform discharge was also similarly observed during successive application of discharge currents from a spark discharger, which commutates the capacitance C in the discharge gap with different time lags relative to the start of the laser pulse. Maximum discharge current was recorded at time lag of 300 μs. At the present time, investigations are being done on the density of generated vapors and on associated electrical and optical discharge properties, which can find use in developing high-power commutators as well as obtaining low-volatility lasing media.

Kondrat'yev, V. N., and I. V. Nemchinov.
Self-similar problems on the movement of a
plane heated material layer with an arbitrary
equation of state. ZhPMTF, no. 5, 1975,
136-145. (Translation)

A self-similar problem is discussed of the nonstationary motion of a plane heated layer, in which energy is released from an external source at constant flux density, q_o. The self-similar variable $\mu = m/t$, where m = Lagrangian mass coordinate and t = time. Characteristic values of velocity, density and pressure are time invariant. For the problem considered it is necessary that energy flux density q is dependent only on μ; thus q(μ) could be an arbitrary function expressible in tabular form.

Examples are cited of real physical processes, in which the mass of the energy-yielding region increases linearly with time. It is assumed that the equation of state is of arbitrary nature, and can be expressed in tabular form. This allows one to specify the gas-forming state of the substance at arbitrary variable adiabatic exponent, as well as the condensed state and two-phase state. Results are described of a solution to the considered problem in the case of heating a half-space bounded by vacuum with some concrete equation of state, for different values of flux density q_o and motion velocity M of the energy yielding region.

79

Yanushkevich, V. A. Probability criteria for
shock wave formation during the action of laser
radiation on the absorbing surface of condensed
media. FiKhOM, no. 5, 1975, 9-11.

During the action of laser pulses with finite rise time on the
surface of a semiinfinite absorbing condensed medium, the compression
stress waves generated are not initially shock waves; they become shock
waves only after passing through a certain depth in the medium.   Based
on gasdynamic processes, it is shown that discontinuity in wave parameters
occurs only at a certain distance, y, within the medium; an expression is
derived for this depth.   It is assumed that the considered process is confined
to the region of one-dimensional motion, i. e. does not go outside the limit
of a hemisphere with radius equal to the radius of the interaction spot.   If
the generated waves do not become shock waves in the region of one-dimensional
motion, then they begin to attenuate sharply according to the usual law for
a point source.   Therefore, this condition can be taken as the probability
criterion for shock wave generation.   Calculations conducted for the depth
of shock wave generation in silicon under the action of laser radiation showed
that at pulse duration = 30 nsec and flux density 5×10^8 w/cm^2, y = 0. 84 mm,
which is in good agreement with previous experiments.

Zemlyanov, A. A. Deformation and stability
of a transparent drop in powerful optical field.
IVUZ Fiz., no. 6, 1975, 132-134.

The present work discusses the theoretical destruction of a
liquid drop, subjected to a powerful light field.   Based on the energy balance
of a moving liquid, equations are developed for the ponderomotive force
acting on the drop.   The ponderomotive work is expended on the increase
of surface energy of the drop, viscous dissipation of energy, and kinetic
energy of the liquid.   Equations are obtained for deformation of the drop as
a function of time and incident flux.   In an example assuming a water drop

of 10^{-2} cm. radius exposed to incident radiation at $\lambda = 0.69\mu$, it is shown that oscillatory deformation of the drop gives way to destruction at densities on the order of 10^9 w/cm^2.

Anisimova, R. N., A. G. Kamenskiy, G. R. Levinson, A. N. Sviridov, and V. I. Smilga. A projection method of laser processing of thin films. PTE, no. 1, 1976, 225-226.

This paper suggests a method for processing thin films by laser radiation, which obtains holes and cuttings of micron dimensions at comparatively small optical path length. The optical scheme is shown in Fig. 1. Dimensions of the hole in opaque mask 2 equal the size of desired
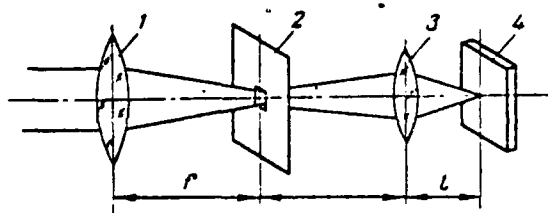

Fig. 1. Optical layout.
1 - focusing lens; 2 - mask; 3 - objective;
4 - treated film.

hole in film 4, so that holes of different sizes can be obtained simply by changing masks. Likewise, cuttings of different dimension in the film could be obtained by moving the film specimen between pulses.

Based on the suggested method, experiments were conducted with a resistive CrSiO film, using a rectangular mask of 50 x 50μ, lens f = 160 mm and objective OK-10 (F = 15.7 mm). Dimensions of the obtained holes in the film equalled 5 x 5μ at layer widths <0.5μ. Advantages cited for this method include increasing the percentage of effective laser radiation; obtaining micron-size holes in films with comparatively long-distance objectives; a significant decrease in optical path length; and increased stability

in results of thin film processing. Fig. 2 shows the relative improvement using the proposed method over results of processing in the focal plane.
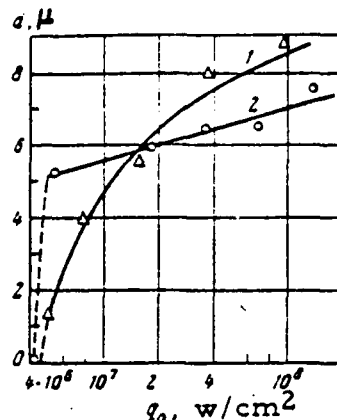
Fig. 2. Hole size in 600A Cu film vs. radiation density.

1- in focal plane; 2- using the authors' method.

Fedoseyev, D. V., G. G. Lopatina, I. G. Varshavskaya, A. V. Lavrent'yev, and S. V. Bantsekov. Using IR laser heating for thermo-physical measurements. TVT, no. 4, 1975, 883-884.

This paper describes one of the possible methods of using an IR laser for approximate measurement of the coefficient of thermal conductivity and degree of blackness.

Specimens of various solids of 6-7 mm diameter and 1-1.5 mm thickness were irradiated by an LG-25 CO_2 laser with beam power > 25 watts, operating in a c-w regime; beam diameter = 10 mm; angular divergence = 40 min. Irradiation was conducted in a spherical reactor with NaCl windows, inside which specimens were placed, and a vacuum unit for pressure down to 10^{-5} torr. Specimen brightness temperature was measured with a UMP-043 micropyrometer.

Expressions are derived for calculating thermal conductivity coefficient χ and blackness degree ϵ. Based on measured values of brightness temperature, χ and ϵ were determined for a series of specimens, results of which are shown in Table 1. These results are in good approximation with known data. Another series of experiments conducted at atmospheric pressure showed that it is necessary to take into account convection and conduction effects in their thermal conductivity coefficients, in spite of their small dimensions. The authors point out that a similar method could also be used for a nonstationary way of determining thermal conductivity coefficient and specific heat.

Table 1. Results of measurements.

Material	Temp. $^{\circ}K$	χ cal/cm. sec $^{\circ}K$	ϵ
Alundum	1200÷1300	$2,4 \cdot 10^{-2}$	0,75
"	1400÷1500	$3,4 \cdot 10^{-2}$	0,35
Niobium oxide	1100÷1500	$1,2 \cdot 10^{-3}$	0,8
Yttrium oxide	1100÷1300	$1,1 \cdot 10^{-3}$	0,10
"	1300÷1650	$2 \cdot 10^{-3}$	0,13
Boron nitride (cubical)	1100÷1200	$1 \cdot 10^{-2}$	0,4
"	1300÷1600	$1 \cdot 10^{-2}$	0,5
Boron nitride (hexagonal)	1100÷1200	$3,7 \cdot 10^{-2}$	0,4

Hanic, F., and J. Straselsky. A method and
apparatus for heating poly- or single crystalline
specimens to 3300° for high-temperature phase
and structural analysis. Czechoslovak Patent
No. 149538, published 15 July 1973. (RZhMetal 15I,
1/76, #11867P)

A crystal heating device is introduced in which the specimen
is mounted on the goniometer head of a precision X-ray camera, and heated
by a CO_2 laser. A uniform and controlled heating to 3300° is achieved,
using a special focusing device. Photographic recording of X-ray diffraction
lines on separate segments of the X-ray film is provided for obtaining
a series of reflections at different temperatures on a single film. An optical
fiber micropyrometer records temperature. One or two lasers may be
used to heat the specimen.

Mirkin, L. I. Fizicheskiye osnovy obrabotki
materialov luchami lazera (Physical principles
of laser beam processing of materials). Moskva,
Mosk. un-t, 1975, 384 p. (RZhF, 9/75,
#9D950 K). (Translation)

This book gives general information on changes in structures
and properties of materials induced by laser beams. Possibilities are
discussed of using laser beams for strengthening as well as destruction of
metals, alloys, semiconductors, dielectrics, polymers and glass. Applications
of laser beams are outlined for surface saturation and for reduction of
chemical compounds with changes in mechanical and other properties.
Descriptions are given on the laser processing of materials in different
fields of technology. The book is of interest to specialists in mechanical
engineering, solid-state physics, and to engineers working in different
industrial fields (metallography, thermal and mechanical treatment of metallic

and nonmetallic materials, electron technology, optico-mechanical industry).

Uglov, A. A. Seminar on Physis and Chemistry
of Material Processing by Concentrated Energy
Flux). FiKhOM, no. 5, 1975, 139-140.

The regular 52nd Seminar on Physics and Chemistry of
Material Processing by Concentrated Energy Flux was held in November
1974 in the Baykov Institute of Metallurgy under the chairmanship of
Academician N. N. Rykalin. Seventy people took part from various
organizations in the USSR; subjects discussed were dedicated to the
thermophysical problems of different technological processes, some of
which are as follows.

A. N. Veretentsev discussed the solution of boundary problems
with moving boundaries for one limiting case. Here boundary problems are
analysed for cases where solutions are obtained for confined regions, having
one or two moving boundaries.

V. V. Ivanov and K. V. Prushkovskiy presented a paper on
investigating the radiant heat exchange in the boundary layer of an absorptive
gas. Numerical investigations were made of radiant heat exchange processes
in the boundary layer of an emissive and absorptive gas. A parametric
analysis is given and the Nusselt number is determined.

M. I. Tribel'skiy reported a study on the shape of the liquid
phase surface during fusion of a solid by a laser beam of moderate intensity.
The steady-state regime of the fusion of an absorbing solid body under the
action of laser pulses in analysed. Analytical equations are derived for
confined problems of hydrostatics and kinetics of evaporation, which describe
the deformation of a free fusion surface by reactive vapor pressure. Self-

oscillations are discussed of the free fusion surface, arising from the action of laser pulses. It is shown that the maximum amplitude always has a mode which corresponds to the fundamental natural frequency. This problem is of interest for analysing the kinetics of liquid metal spill during laser welding.

N. A. Avdonin discussed a mathematical description of the hardening processes of fusion, and solutions taking into account the kinetics of internal crystallization. The author discusses the process of hardening for the case when supercooling is present in the fusion and it is necessary to take into account the internal effect during crystallization.

M. I. Tribel'skiy in a second paper discusses fusion of an overheated polycrystalline body. Overheating of polycrystal occurs during an interval which is much less than the characteristic time of fusion, with fusion subsequently occurring as a result of accumulated internal energy. Differential equations of infinite order, which determine the motion of the fusion front, are obtained with the use of Stefan's law, and solutions are obtained analytically for processes at the beginning and end of the fusion process.

Uglov, A. A. Seminar on Physics and Chemistry of Material Processing by Concentrated Energy Flux. FiKhOM, no. 5, 1975, 140-142.

This is a summary of the 53rd seminar on Physics and Chemistry of Material Processing by Concentrated Energy Flux, held in the Baykov Institute of Metallurgy, on December 26, 1974. The main topic discussed was the action of laser radiation on metals. Some 80 people attended from various organizations in the USSR; papers reviewed include those by S. I. Zakharov on avalanche ionization and breakdown in dielectrics under

the action of single optical pulses at low and high temperatures; by
V. P. Veyko, et al. on the destruction mechanism of thin metallic films
under the action of laser radiation; by B. S. Mikhaylov on characteristics
of the interaction of low intensity optical radiation with thin metallic films
in the millisecond duration range; by V. G. Andreyev, A. A. Orlov, and
P. I. Ulyakova on the mechanism of discrete point destruction of glass by
laser radiation; and by B. M. Kozlov, B. B. Krynetskiy, et al. on
characteristics of the dissociation of a superheated metastable liquid under
conditions of evaporation.

5. Laser-Plasma Interaction

Basov, N. G., V. B. Rozanov, and N. M.
Sobolevskiy. Laser thermonuclear synthesis
and energy of the future. IAN Energ, no. 6,
1975, 3-17.

Dr. N. G. Basov and coworkers have assessed the laser
fusion picture at length in an article in the December 1975 issue of
Energetika i transport. In reviewing the mechanics of the laser-induced
thermonuclear reaction, Basov emphasizes one inherent advantage,
which is that the rapid generation of neutrons in the order of a nanosecond
or less reduces the confinement interval substantially, which is a critical
problem in most fusion studies.

Assuming that laser fusion technology is at hand, Basov
postulates several types of fusion power plant. The one favored by him
would be a hybrid type in which the fusion energy is used for fission of
a second fuel, as this would yield more efficient energy conversion. Such
a plant could be "clean" without undue difficulties, and could operate
profitably even with a laser of the presently low efficiency of Nd glass,
which the Soviets favor.

Recent work in the US and USSR shows that laser fusion is
now a proven technology, according to Basov, and it requires only a
proper application of engineering effort to reduce it to economic practice.

Basov, N. G., A. A. Kologrivov et al.
Observing the compression of hollow micro-
spheres under laser irradiation. ZhETF P,
v. 23, no. 8, 1976, 474-477.

Continued tests with the "Kal'mar" nine-beam laser
system at FIAN are described. The object was to observe the heating

and compression dynamics of various evacuated microspheres, including SiO_2, Al_2O_3 and polystyrene specimens with 50-200 microns radii and wall thickness from 1.5 to 7 microns. The usual Nd glass system was used, but with a YAG control laser, resulting in a generated linewidth on the order of 10A. Relatively long pulses, on the order of nanoseconds, were used at incident energies up to 100j and power densities to 10^{13} w/cm^2.

The test consisted principally of recording x-radiation from the exposed target surface, which revealed the effects of non-sphericity and nonuniform pellet wall thickness. In addition, a densitometry technique was used which registered a bright center as well as a bright outer shell or halo around the exposed microsphere. The authors note that in contrast to the results using picosecond pulses, in this case the outer bright shell was larger than the initial microsphere diameter; the same was observed for filled microspheres.

Gamaliy, Ye. G., S. Yu. Gus'kov, O. N. Krokhin, and V. B. Rozanov. Hydrodynamics of laser plasma, taking into account particle kinetics, resulting from fusion reaction. Fizika plazmy, no. 6, 1975, 904-911.

A hot laser plasma (1-10 kev), where intensive thermo-nuclear reactions take place, consists of a number of high-energy particles (energy ~ 1 Mev), i. e. products of thermonuclear reactions, along with deuterium and tritium nuclei and electrons. During reactions, these fast particles scatter significantly beyond the boundary of the plasma, carrying with them mass and energy from the reaction zone.

The present work considers an approximate solution of such a plasma state, using hydrodynamic equations in which expressions are introduced to take into account the kinetic effects of these particles. To do this, the laser plasma is considered as two groups: 1) cold particles, consisting of deuterium, tritium nuclei and electrons with Maxwellian distribution and with relatively low temperature, 1-10 kev; 2) fast particles, consisting of products of thermonuclear reactions and

particles formed in the DD-reaction of tritium. Hydrodynamic equations are derived for cold particles and kinetic equations for fast particles. Based on the distribution function of cold particles, the hydrodynamic equations are solved, taking into account transference of impulse and energy from fast particles to cold particles as a result of elastic collisions. The result of introducing the kinetic effects of fast particles on the behavior of cold particles is estimated, which leads to the burnout of cold particles as a result of the D-T reaction. It is pointed out that in the case of a confined laser plasma, the process of impulse and energy transfer to plasma and the subsequent decrease of its density and specific energy owing to burnout could have a significant effect on the plasma motion.

Gamaliy, Ye. G., V. B. Rozanov, and N. M. Sobolevskiy. **Possible diagnostics of target density for laser thermonuclear fusion from the thermonuclear neutron scattering in the target material.** KE, no. 11, 1975, 2537-2540.

The possibility of diagnosing the density of a hot dense plasma, generated during target irradiation for laser thermonuclear fusion, based on neutron spectra, was previously discussed in a work by Afanas'yev, Basov et al (KE, 1975, 1816). Since thermonuclear neutrons undergo scattering, depending on the optical length of the neutron path and consequently on the density of the scatterer, it is possible to obtain information on target density by measuring neutron spectra. The present work considers scattering of thermonuclear neutrons, generated during heating and compression of a $(CD_2)_n$ target by target nuclei. The target considered is spherically symmetrical with some density profile $\rho(r)$, where r is the radius. DD neutron spectrum distortions due to scattering in the above target are calculated by the Monte-Carlo method. Calculations are made for two different profiles of target core density: a) $\rho(r)$ = constant; and b) $\rho(r) = 50 + 0.525r^4 - 0.070r^5$ (in g/cm^3).

Spectra of scattered neutrons for targets with these two profiles are
plotted. It is shown that the number of scattered neutrons, n, is
undoubtedly related to the optical thickness along the target radius.
In the case of $\rho(r)$ = constant, n = const $\rho^{2/3}$. The authors conclude that
the present results may be used for diagnostics of experimental target
density.

Anisimov, S. I., M. F. Ivanov, P. P.
Pashinin, and A. M. Prokhorov. Gaseous
shell target for laser initiation of thermo-
nuclear reactions. ZhETF P, v. 22, no. 6,
1975, 343-346.

The present work suggests a new method of obtaining gaseous
shell targets for laser thermonuclear reactions. The proposed target is
actually developed during the irradiation process, wherein a gaseous
mixture of deuterium and tritium is subjected to optical breakdown. Spherical
shock waves, propagating from the point of breakdown, produce a steep
inhomogeneous density profile; practically all matter initially occupying the
volume is then found at the periphery due to shock wave action, and a
comparatively cold plasma shell is formed whose relative thickness is on the
order of 10%. The density of matter at the center is very low, but energy
density due to high temperature is comparable to the energy density at the
shock wave front.

The gaseous shell thus formed is used as a laser target and
is irradiated symmetrically by a pulse or series of pulses. The process
of shell collapse during irradiation in this case is found to be significantly
different from the usual picture, and a detailed description is accordingly
given of the dynamics of target shell collapse. Problems with the proposed
method lie in obtaining an ideally spherical target, its positioning in the
optical system focus, and shielding of the chamber walls against neutron
flux, charged particle flux and x-radiation; besides these, there are a
number of other problems connected with the irradiation mode.

A numerical calculation is given of the implosion process of a D-T mixture for a laser energy of about 100 j. Thermonuclear yield in the calculation was naturally low, the total number neutron yield being 10^9. Neutron yield could be increased by several times by slight changes in pulse duration and switching time. It is noted that the best results could be obtained by pulse programming.

Afanas'yev, Yu. V., Ye. G. Gamaliy, O. N. Krokhin, and V. B. Rozanov. Acceleration, compression and stability of the plane layer of a substance under the action of laser radiation. PMM, no. 3, 1975, 451-457. (Translation)

The transfer of a mechanical recoil pulse to a laser target as a result of evaporation and hydrodynamic scattering of the material by laser radiation has been studied in a number of experimental and theoretical works. It is known that for a sufficiently high radiation flux density, compression waves (especially shock waves) are generated in the bulk material. Hence, if the value of evaporated mass is comparable to the total target mass, then the unevaporated part can be accelerated up to velocities close to the ejecta velocity of the evaporated material, and, under certain conditions this material can be compressed to densities considerably higher than the density of the normal condensed state. This effect is of great interest in general problems of small-particle acceleration up to velocities of 10^5-10^7 cm/sec or higher.

In the present work, a simple gasdynamic model of laser acceleration and compression of a plane material layer is theoretically discussed. Conditions are determined under which a limiting isentropic compression regime occurs, under the above conditions, and stability is investigated. The problem of laser radiation energy transfer to the accelerated layers is discussed as well.

Kaliski, S. Simple averaged solution to the
problem of adiabatic implosion in a spherical
shell. Bull. Acad. pol. sci. Ser. Sci. techn.
v. 23, no. 4, 1975, 157-164. (RZhMekh, 1/76,
#1B202). (Translation)

A simplified model is discussed for obtaining an averaged
solution to problems on concentric adiabatic implosion of thin spherical
shells. Maximum compression and corresponding explosion are estimated
and found to be in good agreement with numerical calculations, within an
order of magnitude. Results of the present work could be used in laser
technology.

Kaliski, S. Laser anti-hydrogen microexplosion.
Bulletin de L'academie, Polonaise des sciences,
Serie des sciences techniques, v. 23, no. 10,
1975, 99(881)-106(888).

The concept of a laser anti-hydrogen microexplosion is
presented and its critical values are assessed for lasers of technically
attainable parameters. Critical values obtained include a density $q = 5 \times 10^{19}$
w/cm^2, laser energy $E_1 = 100$ kj, and $\tau = 2$ nsec. The effect is attained
by applying precompression (10^2 to 5×10^2) of a D-T ball, and making use
of the effect of reduced coefficient of refraction n for cut-off plasma
density.

Results of the present work are obtained with extensive
simplification, and are offered only as rough approximations. The system
proposed here is simple owing to inertia effects, problems of extracting
and preservation of antimatter, etc. The annihilation explosion suggested
would be about 1000 times as effective and strong as the corresponding
thermonuclear explosion for an identical mass of charge, so that it opens

promising prospects in the research of methods of rapid energy
conversion. In view of the smallness of charge, microexplosions may
also find direct nonmilitary applications.

Mak, A. A., A. D. Starikov, and V. G. Tuzov.
Directing and focusing powerful light beams on the
surface of small targets. OMP, no. 1, 1976,
42-44.

A highly precise technique is described for focusing
multiple laser beams on a fusion target. The system uses planar or
spherical simulated targets for adjusting the optical elements, and an
auto-collimator for visual monitoring. The theoretical focusing
precision of this system is given as 0.88 micron; tests show the actual
r.m.s. error is 2 microns for planar targets and 3.5 microns for spherical
targets. Two variations of the optical system are shown schematically and
their alignment is discussed. The techniques are cited as providing for a
highly precise positioning of the laser beam(s) on the fusion target, as well
as giving a uniform intensity of irradiation over the target surface.

Dymshits, Yu. I., and V. G. Neverov. Direct
experimental observation of the shielding effect
of a plasma flare. ZhTF P, v. 1, no. 12, 1975,
558-562.

Experimental studies are described on the transparency of a
plasma flare, generated by laser irradiation of metals in vacuum, during
flare lifetime and as a function of laser radiation flux. Tests were done on
thin metal foils having a 0.12 mm diameter hole at the focal spot center,
with transmitted and reflected flux recorded. It is shown that absorption

in the plasma occurs in steps in the form of 'flares' and bears a threshold
character. The flare starts obsorbing laser radiation at a moment close
to the time of plasma generation with $T = 4,000-5,000°$ K and a value of
$q \geq 0.59 \, q_{th}$, where q_{th} = threshold flux density when plasma appears on the
metal surface. Absorption of radiation in the flare intensifies, and the
onset of the shielding effect advances towards the start of the laser pulse,
as q is increased. This effect is shown in Fig. 1, where radiation transmitted
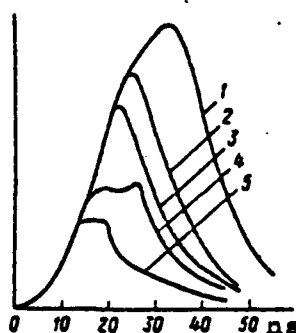through the target hole decreases in jumps, indicating the stepwise

Fig. 1. Oscillogram of incident and laser
pulses: Al target, defocused beam. Oscillogram
reduced to common scale.

1- incident signal; 2 - 3.1×10^7; 3 - $1.1 \times .10^8$;
4 - 2.5×10^8; 5 - 5.6×10^8 w/cm^2.

nature of absorption with increase of flux density.

Relationships are also plotted for the integral (average during
a laser pulse) transmission of the plasma, P_f, as a function of the incident
power density (Fig. 2). Based on the results of plasma flare transmission,
its optical thickness τ is determined, and the relation $\tau(q)$ is evaluated.
Values of laser power density at which optical thickness of the plasma
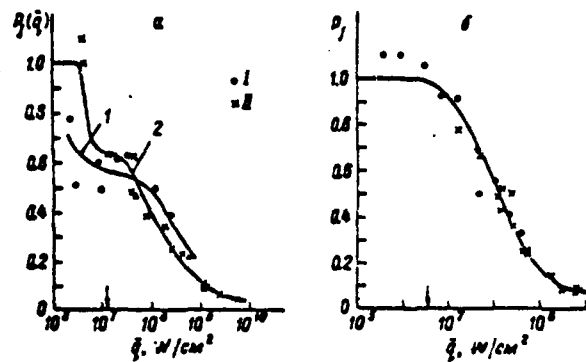flare equals 0.4 are shown in Table 1.

Fig. 2. Integral transmission (average during pulse) through hole as a function of incident power density.

I - Defocused beam (curve 1); II - Focused beam (curve 2); a - Al target; b - Pb target. Arrows indicate threshold plasma generation.

Table 1

Laser power density at optical thickness of plasma flare $\tau = 0.4$ for different materials.

Metal	Experiment		Calculation
	$\tau_f = 0.4$	$\tau_{45} = 0.4$	$\tau_{45} = 0.4$
Al	$1 \cdot 10^8$	$5 \cdot 10^6$	$1.2 \cdot 10^3$
Cu	$1.8 \cdot 10^8$	$1.3 \cdot 10^7$	-
Pb	$1.5 \cdot 10^8$	$4.5 \cdot 10^7$	$5 \cdot 10^7$

The authors point out that discrepancies in experimental and calculated values in Table 1 could be minimized, if the calculations allowed for the increase of absorption coefficient, which is caused by the increase of particle concentration from tunnel ionization of excited atoms in a strong optical wave field.

Afrosimov, V. V., V. P. Belik, S. V. Bobashev, and L. A. Shmayenok. <u>Absolute measurement of photon flux from a laser plasma in the vacuum, UV region.</u> ZhTF P, v. 1, no. 18, 1975, 851-854.

Absolute intensity of vacuum UV radiation from a laser plasma was determined to clarify its possible use in experiments in atom photoionization. A 0.5-mm diameter tantalum wire was irradiated in a vacuum chamber by a Q-switched Nd laser with a nonspherical lens (f = 90 mm). Laser pulse parameters were: energy = 10 j, duration = 40 nsec, beam divergence = 10^{-3} rad; and flux density at the target surface was 2×10^{12} w/cm^2. Absolute photon flux intensity from the laser plasma was measured with a time-of-flight mass-spectrometer, calibrated by a monochromatic electron beam. It was seen that in the region of 400-500Å and 770-800Å the number of photons emitted from the laser plasma equalled $N_1 = (4\pm2) \times 10^{11}$ Å^{-1} ster^{-1} and $N_2 = (1\pm0.5) \times 10^{11}$Å^{-1} ster^{-1} respectively. Estimates showed that at such intensities and with the usual loss of light in the monochromatic channel (relative resolution 1%), the sensitivity of the time-of-flight mass-spectrometer was quite sufficient for studying photoionization processes with cross-sections up to 10^{-22} cm^2. The authors note that the discussed method of measuring the value of pulsed monochromatic photon flux could also be used in the case of soft x-ray flux measurement.

Gerasimov, B. P., V. M. Gordiyenko, and A. P. Sukhorukov. <u>Free convection during photoabsorption.</u> ZhTF, no. 12, 1975, 2485-2493.

Based on the theory of similarity, convection of a medium filling a horizontal tube is theoretically studied during its volumetric heating by a narrow light beam. The average convective flux velocity V is investigated as a function of the beam power and radius for different Prandtl number values.

This relationship takes the form $V = Cq^N$, where C and index N (N = 1, 1/2, 1/3) vary with the increase in developed heat q during transition to different regimes. As such, different regimes of steady-state convection (weak, moderate and strong) are classified according to velocity V, and beam-power boundary values are determined for different convection regimes. For weak convection, velocity is directly proportional to beam power; for moderate, to the square-root, and for strong convection, to the cube-root of the power.

The theory was tested by the probe arrangement shown in Fig. 1, in which the onset of nonstationary convection, induced by a CO_2
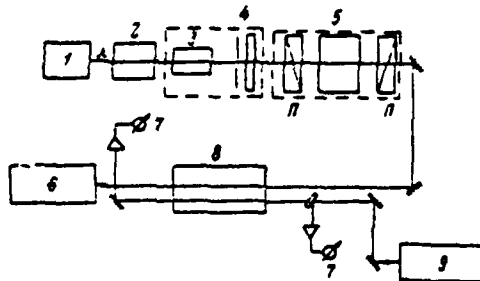

Fig. 1. Convection experiment.

1- counter; 2- shaper; 3,4- photomultiplier;
5- interferometer; 6- He-Ne laser; 7- detector;
8- test vessel; 9- CO_2 laser.

laser beam passing through an air and propane mixture, was detected by the optical disturbance of a parallel He-Ne laser probe beam. Graphical results are included.

Shkedov, I. M., N. K. Zaytsev, and N. Ya.
Shaparev. <u>Effects of an obstacle and ambient</u>
<u>atmosphere on the characteristics of a laser</u>
<u>flare.</u> ZhPS, v. 24, no. 1, 1976, 144-146.

Laser-flare dynamics and spectral characteristics were
studied in the presence of obstacles and in different atmospheres. The
study was conducted using ruby and Nd lasers, operating in a free-running
mode at 1 j. Spectra from a single flare were recorded by an ISP-51
spectrograph. Time scanning of the flare was done by SFR-2M high-speed
camera. The obstacle used was a glass disc shutter rotating at 10,000
r.p.m., and the target was aluminum. Effects of different ambient gases
on flare formation were studied with laser radiation at 0.3j in this case,
the target was metallic sodium. The gases used were argon, nitrogen, air,
oxygen and their mixtures. The tests showed that interposing an obstacle
between the target and laser leads to an increase of spectral line intensity,
time of illumination, and spreading of the flare over the obstacle surface;
this effect increases with decrease in obstacle distance from the target.
The presence of an atmosphere which is chemically active with the target
ejecta products leads to an additional increase of illumination time, brightness
and flare dimensions with increase in pressure. Spreading of the flare on
the obstacle surface leads to an increase in the optical thickness of the
plasma at resonance transitions.

Dymshits, Yu. I. <u>Determining optical thickness</u>
<u>of a plasma flare by measuring its absolute spectral</u>
<u>brightness.</u> ZhTF P, v. 1, no. 12, 1975, 554-558.

Two methods are described for measuring optical thickness
of a plasma flare generated by laser radiation interaction with a metal
surface.

The first method makes use of spectral brightness b, temperature T, absorption coefficient K_λ and thickness d of the plasma layer. Optical thickness τ_λ is determined by measuring the brightness in two directions with differing d and solving a system of two equations. The experimental setup for measuring brightness is briefly outlined and optical thickness τ_λ is calculated; the laser wavelength used in this case was $\lambda = 0.37\mu$. Based on the obtained value of $\tau_{0.37}$, the optical thickness τ for laser radiation at $\lambda = 1.06\mu$ in the direction of beam axis is calculated by means of the Kramer-Unsold formula. Measurements of τ for different values of radiation flux density q at different moments of time showed that when $q \geq 10^8$ w/cm^2, the plasma flare absorbs a great portion of the laser energy at the end of pulse duration. The shielding effect of the flare weakens with decrease in q. The mimimum value of q at which appreciable absorption ($\tau = 0.4$) is observed at the end of pulse duration (60 nsec) was found to be 4×10^7 w/cm^2 for aluminum, and 8×10^7 w/cm^2 for copper.

The second method makes use of the brightness temperature T_b. A relation is obtained between T_b and τ_λ, and based on experimentally measured values of T_b from the curve $T_b(q)$, τ_λ at $\lambda = 0.37\,\mu$ is determined. Optical thickness τ for $\lambda = 1.06\,\mu$ is then again calculated with the Kramer-Unsold formula as in the first method. The value of flux density q at which plasma flare strongly absorbs laser radiation is calculated from $\tau(q)$. It was found that at $\tau = 1$, $q = 10^7$ w/cm^2 for lead, 6×10^7 w/cm^2 for Al, 8×10^7 w/cm^2 for Cu and 1.7×10^8 w/cm^2 for graphite.

The author notes that this minimum value of laser flux density q leading to strong absorption in plasma, calculated by the cited methods, is close to the critical value of q as reported in previous works.

Dreyden, G. V., G. V. Ostrovskaya, N. A. Pobedonostseva, and V. N. Filippov. Resonance interferometry of a laser flare in Li-Pb alloy targets. ZhTF P, v. 1, no. 2, 1975, 106-110. (RZhRadiot, 7/75, #7Ue172). (Translation)

Scattering of neutral atoms in a laser plasma flare was investigated in targets made of Li-Pb alloys. Resonance interferograms were obtained by means of a tunable dye laser which allowed a wide range of sensitivity variation in determining Li atom concentration in the plasma, by changing the difference between probe radiation lines and resonance doublets of lithium (λ_{01} = 6707.1Å, λ_{02} = 6707.9Å). Based on the results of processing the interferograms corresponding to different scattering stages of the flare, the spatial distribution of Li atom concentration was obtained along the laser beam axis.

It was observed that the initial process of scattering starts with the plasma from the target; it is then supplemented by condensation of lithium on the target, which leads to a decrease of N_{Li} near the target surface. The absence of axial symmetry and considerable inhomogeneity in the plasma prevented obtaining the radial distribution of atomic concentration. From obtained interferograms, the displacement of interference bands near the laser beam axis was found to decrease, leading to the conclusion that during flare expansion, a shell is formed in which the density of Li-atoms is higher than in the central region of the flare.

Kologrivov, A. A., Yu. A. Mikhaylov, G. V. Sklizkov, S. I. Fedotov, A. S. Shikanov, and M. R. Shpol'skiy. Using type UF-R and UF-VR photographic films for diagnostics of a laser plasma based on continuous x-radiation in the 0.1 - 1nm spectral range. KE, no. 10, 1975, 2223-2230.

Results are described of experimental investigations on the possibility of using type UF-R and UF-VR photographic films for

diagnostics of a high-temperature plasma, generated during focusing of single-beam Nd laser radiation (1.06 μ) on the plasma surface of a massive Al target. Diagnostics would be based on continuous x-radiation from the plasma in the 0.1 - 1 nm spectral region. Laser pulse parameters were: energy = 30 j, duration τ_i = 3-4 nsec, contrast = 10^6, and divergence = 5×10^{-4} rad. Radiation was focused by a lens at f = 10 cm on an Al target of 1.5 mm thickness in a vacuum chamber at 2×10^{-6} torr. Flux density on the target was 10^{14} w/cm^2. Filters used were Be and Al foils of 100-2500 μ and 20-200 μ thickness respectively. X-radiation was recorded by multichannel detectors, in which the sensing elements used were type UF-R and UF-VR photofilms. A parallel set of experiments were conducted with a nine-channel laser system, in which x-radiation was recorded in two mutually perpendicular directions. In this case, the nine laser beams were focused on the Al target into a single beam of 143 cm^2 cross-section with flux density up to 10^{15} w/cm^2. A detailed description is given on the photofilm method of recording continuous x-radiation, and an expression is derived for the sensitivity of the films. The application of this method for measuring electron temperature of the plasma in the flux density range of 10^{13} - 10^{15} w/cm^2 is demonstrated and determination of the relative sensitivity of UF-R and UF-VR photofilms to continuous x-radiation is discussed theoretically.

For interpreting the obtained results, it is necessary to relate darkening density of the photofilm, D, with spectral distribution of the recorded radiation. Comparison of experimental results with those of previous data on the sensitivity of photofilms to radiation at 0.1 - 1 nm wavelengths shows that the upper limit of the sensitivity of photomaterials is approximately 2 - 3 x 10^7 quanta/cm^2 for darkening density D = 1.0, and 10^6 quanta/cm^2 for D = 0.2. Results show that the most suitable photo-material for recording continuous x-radiation in the above spectral region is the type UF-VR photofilm. X-ray recording in the shorter wave spectral region (less than 1 nm) leads to a decrease in quantum sensitivity of the photolayers due to the decrease in volume absorption coefficient; in such cases it is advisable to use intensifying grids.

Boyko, V. A., O. N. Krokhin, S. A.
Pikuz, A. Ya. Fayenov, and A. Yu.
Chugunov. Studying conical cumulation of a
laser-produced plasma by x-ray spectroscopy.
Fizika plazmy, no. 5, 1975, 782-785.

Conical cumulation of a laser-produced plasma was
investigated by x-ray spectroscopy techniques. Laser emission was
focused on two types of targets, namely flat targets and on targets
consisting of a hollow cone (apex angle about 90°). CD_2, Mg, Al, P,
S, Sc, Ti, V, Fe, Y, Zr, Nb, and Mo targets were used; effective
ionic charges in the plasma were $Z_{eff} \sim 8/3$ - 33.

The study shows that the spectra I_0 (E_0) for continuous
x-rays are identical for both target types; for $Z_{eff} < 16$, they deviate
more noticeably from Maxwellian distribution; for $Z_{eff} \sim 30$, the
spectrum is identical to that for bremsstrahlung. However, in the
conical target, temperature T_{eff} is somewhat higher (for Mg, about
0.8 keV vs. about 1.1 keV for the flat and conical cases, respectively).
In addition, at $E_0 \sim 100$ keV, the intensity of x-rays, I_0, is somewhat
higher in the conical case. It is noted that the "hysteresis effect"
(Afanas'yev, et al., 1973) was not observed. Neutrons are detected only in
the conical case; in 30% of the flares, about 10^3 neutrons were detected.
However, line x-ray spectra differ in the two target cases. In the first
case, the maximum coefficient of reflection in incident radiation is
about 3% at $Z_{eff} > 10$, and 8-10% for the CD_2 target; in the second case,
it is about 1%.

Boyko, V. A., O. N. Krokhin, S. A.
Pikuz, A. Ya. Fayenov, and A. Yu.
Chugunov. Investigating continuous x-ray
spectra of a laser plasma and reflection of
heating radiation. Fizika plazmy, v. 1, no. 2,
1975, 309-319.

Investigations were conducted of the processes which
follow the absorption of heating radiation during focusing of laser

beams on plane targets. These include radiation from the plasma and generation of continuous x-radiation whose spectral distribution depends on the electron energy distribution in the plasma. The source used was an Nd laser with pulse energy up to 80j; rise time, 0.8 nsec.; pulse width, 1.8 nsec.; divergence $= 3 \times 10^{-4}$ rad.; and contrast $= 10^5$. The experimental arrangement is shown in Fig. 1. Focal spot diameter was 0.08 mm and incident flux density $q = 5 \times 10^{14}$ w/cm^2. Targets used were bulk CD_2; Al; Mg; Y; Nb; Zr; Pb; 70% CD_2 + 30% Al as well as thin films and foils of thickness 0.1 - 0.2 mm (CD_2; Al).
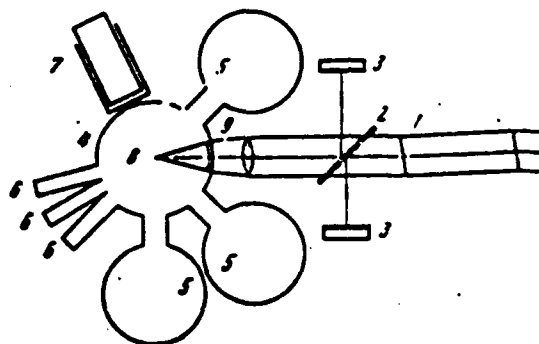

Fig. 1. Experimental setup.

1- Final amplification stage with active rod of 64 mm; 2- splitter; 3- calorimeters for incident and reflected energy; 4- vacuum chamber; 5- crystal spectrograph; 6- x-ray scintillation detector; 7- neutron counter; 8- target; 9- two-component objective.

Previous works have indicated that in a number of cases the electron distribution in a laser plasma deviates from the Maxwellian distribution. The present authors made a spectral investigation of the continuous plasma x-radiation containing ions with ionisation up to $Z = 50$, in the photon energy range of 5-21 kev. A comparison of experimental data with the theoretical concept of parametric instability enabled the authors to investigate the possible mechanisms which are responsible for the non-Maxwellian energy distribution of electrons. Measurements of the reflection coefficient of heating radiation for different

targets yielded the relation of maximum reflection with maximum hard
($\sim$ 21 kev) x-ray intensity and maximum multiplicity of ions in the
plasma.

Results indicate that at some value of q_{thr} , depending
on parameters of heating radiation and the target material, highly energetic
photons are generated, causing the deviation of electron energy distribution
from Maxwellian. This deviation at constant q increases with the decrease
of effective charge Z_{eff} of ions in the plasma. The deviation in energy
distribution function is connected with the development of plasma
instability, and the most significant role in this is played by aperiodic
instability and dissociation of two plasmons. Studies of continuous x-ray
spectra and the spatial distribution of electron temperature by x-ray
spectroscopy of multiply charged ions, in the case of composite targets
(70% CD_2 + 30% Al), showed that the forms of continuous radiation spectra
of these targets do not differ significantly from those of homogeneous
CD_2 targets, while the intensity of the former is considerably higher.

Reflection coefficient R strongly depends on focusing
conditions. Thus for targets with Z > 10, a change in target position
by 1.5 mm led to a decrease of R from 3 to $\sim$ 0.3%. For CD_2 ($Z_{eff} \sim$ 3),
maximum reflection amounted to 8 - 10%. In experiments with conical
cumulations, the maximum value of R was practically independent of
Z_{eff} and equalled about 1%.

Kovalev, L. D., N. V. Larin, and G. A.
Maksimov. Mass-spectrometric investiga-
tion of ion acceleration during laser plasma
scattering of binary compounds. ZhTF P,
v. 1, no. 17, 1975, 798-801.

The mechanism of ion scattering was experimentally
investigated by measuring energy characteristics of singly-charged
ion spectra during laser irradiation of the following materials: Cd,

CdTe, Si, SiO, SiO_2, SiC, Al, Al_2O_3. Tests were done using a time
of flight mass-spectrometer with a laser ion source. The laser used
was a Q-switched Nd glass type, thus producing only atomic mass spectra.
Power density on samples was 2×10^9 w/cm^2; the plasma generated
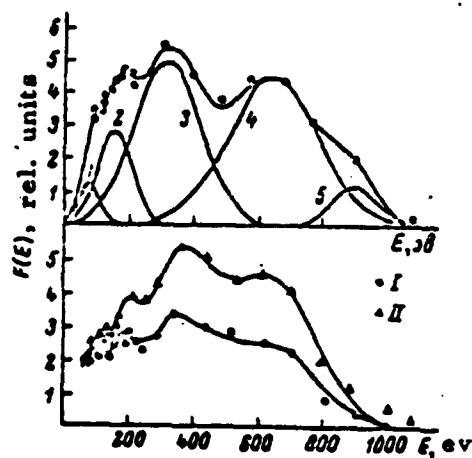expanded freely in vacuum.

Fig. 1. Energy spectra of singly
charged ions.

I- Cd^{+1}; II- Te^{+1}. Curves 1-5
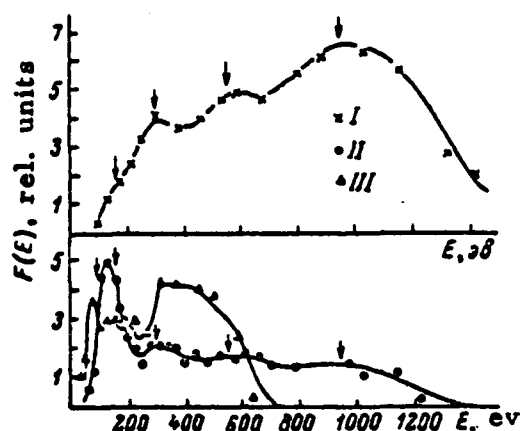are obtained from Gaussian
distributions.

Fig. 2. Energy spectra of ions of
SiC plasma.
I- Si^{2+}; II- Si^{1+}; III- C^{1+}. Arrows
show calculated values of average ion
energy.

The first maximum in Fig. 1 (energy about 100 ev)
corresponds to singly charged ions, while the remaining represent
recombination ion maximums of higher charge. It is seén that the
position of the maximum on the energy axis for Cd^{+1} ions from metal,
as well as from CdTe, is the same, and the maximum for Te^{+1}
coincides with them (Fig. 1).

The positions of maxima for lighter ions also do not
change during their transition from element to compound; however, they
are observed at lower energy as compared to Cd, e.g., in the case
of Si^{+1} and C^{+1}, from SiC (Fig. 2). Measurements showed that maxima
corresponding to singly charged ions are absent in doubly-charged ion
spectra (Fig. 2); positions of the other maxima coincide with those of
singly charged ion spectra. It is concluded that multiply-charged ions,
maintaining their average energy, recombine creating maxima in the
ion spectra of lower charges.

Based on Gaussian distribution of energy spectrum,
expressions are derived which correlate various energy parameters,
taking into account hydrodynamic acceleration of ions. It is shown that

107

recombination of ions takes place mainly at the conclusion of the accelera-
tion process. Values of hydrodynamic acceleration, independent of
combinations, equal 40 ± 5 ev for Cd^{+1}, Te^{+1}, Si^{+1}, and Al^{+1} ions, and
60 ± 3 ev for O^{+3} and C^{+1}, which agree well with previous work.

Zakharenkov, Yu. A., N. N. Zorev, O. N.
Krokhin, Yu. A. Mikhaylov, A. A. Rupasov,
G. V. Sklizkov, and A. S. Shikanov. Inves-
tigating laser radiation interaction with plasma
corona at flux densities of $10^{14} - 10^{15}$ w/cm^2.
ZhETF, v.70, no. 2, 1976, 547-559.

Results are described in detail of experimental
studies on the interaction of laser radiation with a plasma, generated
during heating of plane targets at flux density $q = 10^{14} - 10^{15}$ w/cm^2.
Heating of plasma was done with the 9-channel Nd laser system shown
in Fig. 1. Tests were done using the following methods: 1) high-speed
interferometry with slit scanning of the image in an image converter tube;
2) recording continuous x-radiation in the spectral region of 1 - 10Å,
using x-ray photofilms; 3) recording luminous emittance of the plasma
in the soft x-ray region with spatial resolution (multichannel camera
obscura); 4) recording luminous emittance of the plasma at harmonics
of the incident laser radiation with time and spatial resolution; 5) record-
ing spectral components and incident and reflected energy from plasma
emission. In addition, detectors for recording neutrons and hard x-rays
($h\nu \gtrsim 100$ kev), and x-ray spectrographs in the 10 - 1000Å in the region
were used during experiments. Several typical results are illustrated
with graphs and photos.
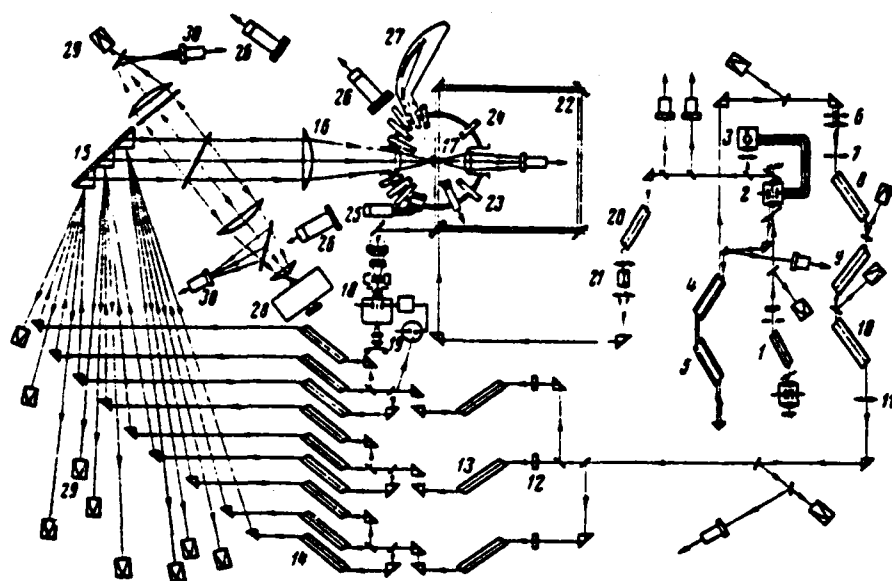
(Fig. 1 on the following page)

Fig. 1. Experimental device.

1- Q-switched Nd laser with Kerr cell; 2- Kerr
shaping gate; 3- discharger with laser ignition;
4,5- amplification stages with dual channels;
6- long-focus lens; 7- diaphragm; 8-10- final
preamplifier stage; 11- lens; 12- bleachable
filters; 13,14- power amplifier stages;
15- 9-prism mirror; 16- focusing system;
17- vacuum chamber; 18- photodetector;
19- discharger with laser ignition for control-
ling photodetector; 20- amplifier; 21- KDP
crystal; 22- interferometer; 23- multichannel
film detector; 24- multichannel camera obscura;
25- multichannel hard x-ray recording system;
26- neutron detector; 27- x-ray spectrograph;
28- monochromator (spectrographs VMS-1 and
ISP-51, not shown in sketch); 29- calorimeter;
30-coaxial photoelements.

The present work is a continuation of previous experiments, conducted by the authors and others, connected with the interaction processes of laser radiation with plasma. Compared to previous investigations, where the density profile was obtained up to values not over 5×10^{19} cm^{-1}, in the present work using special complex methods, the authors establish density profiles in the range of 10^{18} - 2.4×10^{21} cm^{-1} (critical density for $\lambda_0 = 1.06\mu$ was 10^{21} cm^{-1}), and thus obtain various new data on corona parameters. Evolution of the density profile is accompanied by the occurrence of perturbations in corona profile (cavitons). Distinctive features are observed in the region of critical density. Formation of jets were detected in the hot region of the plasma, which was recorded by x-radiation. Results are described of detailed investigations on scattered and reflected radiation at frequencies of ω_0 and $2\omega_0$, which indicated the presence of a red shift in the peak of the second harmonic line.

Kozlov, G. I., V. A. Kuznetsov, and
V. A. Masyukov. Investigating radiation
losses of a xenon plasma in a continuous
optical discharge. Fizika plazmy, v. 1,
no. 5, 1975, 830-835.

The authors investigate a method for direct measurement of radiation losses of a xenon plasma at temperatures of 8,000 - 14,000 K, by means of a continuous optical discharge. The important factor in determining radiation loss is the integral emissive power, E_s, in watt/cm$^3 \times$ster, which takes into account line radiation, recombination radiation, and bremsstrahlung.

Experiments were conducted for measuring the value of E_s directly as a function of temperature, using the device and procedure described previously by the authors (ZhETF, 66, 1974, 954; OiS, 37, 1974, 1049). The continuous optical discharge consists of a plasma formation of dimension $\cong$ 5 mm, which is sustained by c-w radiation from a 1 kw CO_2 laser. The temperature profile of the discharge in

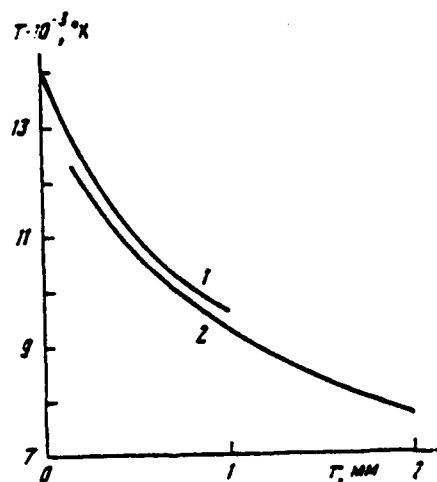the investigated cross-section is shown in Fig. 1. From the obtained

Fig. 1. Temperature profile in discharge at xenon pressure 2 atm, obtained from absolute intensity of 5292 XeII ion lines (1) and absolute value of the intensity of continuum at 5300 Å (2).
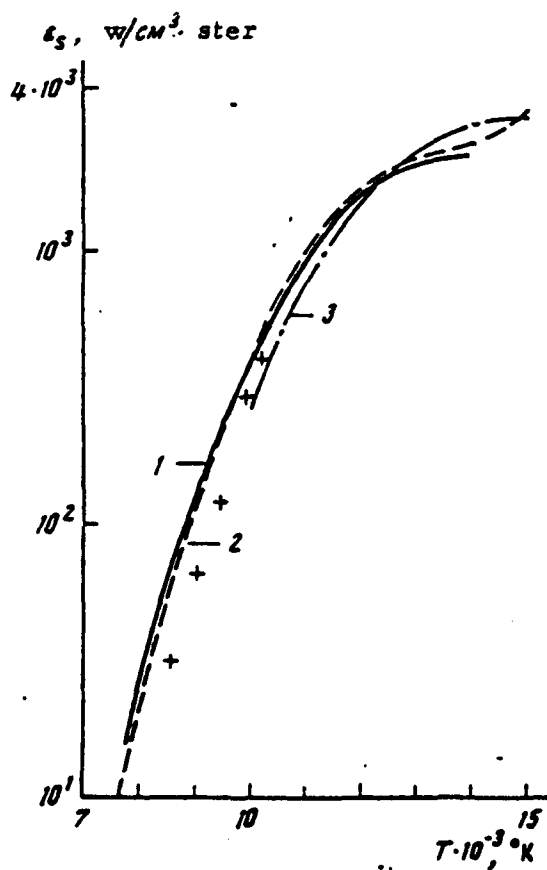

Fig. 2. Experimental (1) and calculated (2, 3) values of emissive power $E_s(T)$ of xenon at p = 2 atm. Crosses show results of measurement.

temperature profile $T(r)$, and computation of the profile of integral emissive power $E_s(r)$, a new curve is obtained which gives the temperature dependence of integral emissive power $E_s(T)$ (Fig. 2). Net error in determining $E_s(T)$ for $T = 10,000$ K and pressure $p = 2$ atm are also shown in Fig. 2. Experimental results are found to be in good agreement with calculations.

Lovetskiy, Ye. Ye., A. N. Polyanichev and
V. S. Fetisov. Recombination and acceleration
of ions in a laser plasma. FP, no. 5, 1975,
773-781.

Expansion in vacuum of a laser-produced two-component (ion) plasma bunch is described by a set of gas dynamic equations in Lagrangian mass coordinates with allowance for recombination and ionization. The equivalent set of difference equations is solved numerically for Li and LiH plasmas and different initial temperatures T_0 and radii R_0 of a bunch.

The resulting spatial distribution patterns of different ions show that triple recombination of ions with an electron is the principal process in the expanding plasma bunch. The energy distribution patterns show that ions are strongly accelerated during expansion, with final kinetic energy of Li^+ and H^+ ions exceeding in some cases their initial thermal energy by two orders of magnitude. The cited theoretical recombination and acceleration kinetic patterns agree well with the earlier experimental data, particularly with the data of Rumsby and Paul (Plasma Phys., v. 16, 1974, 247).

Tests are described on probing of a laser plasma, in
which part of the incident laser beam is split off and redirected through
the generated plasma. Attenuation characteristics in the plasma were
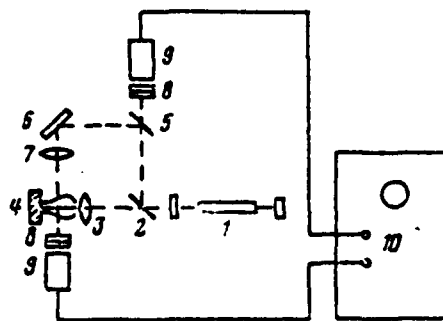then studied.

Fig. 1. Optical sketch of plasma experiment.
1- laser; 2, 5- splitters; 3, 7- focusing lens;
4- target; 6- rotating mirror; 8- light filter;
9- photomultiplier; 10- oscillograph.

The experimental setup is shown in Fig. 1. The radiation
source was a ruby laser with resonator using two plane mirrors; the
diameter of the active element was 1.2 cm and its length 12 cm. The
laser was operated in a free-running generation regime at durations
of 400 - 500 μ sec and pulse energy 2 - 6j. Average pulse power density
of incident radiation on the target G = 2.5 - 7 Mw/cm^2; the probe radiation
level was 500 w/cm^2. Targets used were copper, iron and zirconium.

The flare was probed in regions at distances of 1 - 3 mm
from the target. Optical density of the flare was determined from the
ratio of incident and transmitted radiation intensities. Dimensions of
absorbing layers at different time intervals of the flare was observed
with a high-speed camera. Extension of the plasma layer into the

translucence region was measured to be 0.3 - 1.5 cm.

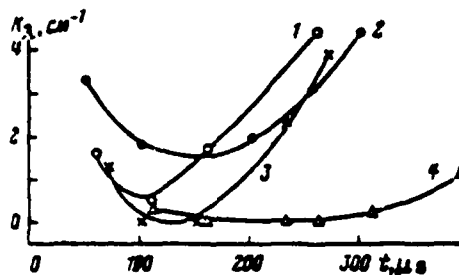The time dependence of the attenuation factor of the probe beam, K_λ, for copper and steel target flares is shown in Fig. 2.

Fig. 2. Time dependence of laser radiation attenuation factor for copper (1,2) and steel (3,4) at flux density $G(Mw/cm^2)$ and distance from target L(mm):

1- G = 7; L = 2; 2- G = 5, L = 1;
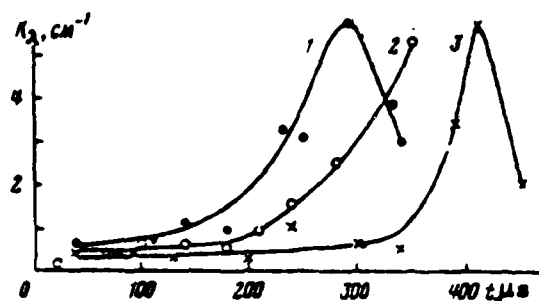3- G = 2.5, L = 1; 4- G = 7,
L = 3.

Fig. 3. Time dependence of K_λ for zirconium at G = 2.5(1); 5(2); 7 Mw/cm^2(3) and L = 3 mm (1,2,3).

A characteristic of these curves is seen to be the presence of troughs in the middle and comparatively high values of K_λ in the beginning and end of pulse generation. Minimum attenuation occurs approximately 100-150 μsec after pulse start for copper and 150-200 μsec for steel. In the case of zirconium, attenuation of the probe beam at pulse start is comparatively small and it reaches its highest value only at the end of pulse generation (Fig. 3).

Mechanisms of the interaction of laser radiation with the flare which leads to variation in its shielding effects, is theoretically explained in terms of destruction of condensates and drop-like particles by powerful laser radiation, and development of nonlinear properties in the plasma.

114

Bychkov, Yu. I., Ye. K. Karlova et al.
Pulsed CO_2 laser with 5 kj energy. ZhTF P,
v. 2, no. 5, 1976, 212-216.

The latest large-volume atmospheric CO_2 laser developed
by Prokhorov's team at FIAN is described and its structural details
given. The laser uses a 270 liter active volume, placed within a 4500 liter
plexiglass-lined steel CO_2 reservoir; active vessel dimensions are 30 x
30 x 300 cm. E-beam pumping is used, employing a multi-needle cathode
with explosive field emission which develops 150 kiloampere, 2 micro-
second pulses at 125 kv diode voltage. Structural details of the diode
and resonator are included.

Tests so far show a stable pulsed output of 5 kj at 26%
efficiency. Increased yield with larger sized optics is anticipated.
Deterioration of the output mirror is mentioned but not detailed. The
design is offered as the most powerful of its type to date.

Kozlov, G. I., V. A Kuznetsov, and V. A.
Masyukov. Studying radiation losses from a
xenon plasma produced by a continuous optical
discharge. Fizika plazmy, no. 5, 1975, 830-835.

Data are given on direct measurement of radiation from
a xenon plasma in the 8,000-14,000K temperature range. Measurement
was done by means of a continuous spark discharge in Xe, generated
by a CO_2 laser at 1 kw and pressure of 2 atm. The test results agree well
with the author's calculations for integral radiation from an optically
thin plasma. A comparison is made with findings of several previous
authors, with some discrepancies noted. The question is also treated
of the fraction of line emission in the integral plasma radiation. It is
shown that in the cited temperature range this amounts to 65-80% for
xenon.

6. SOURCE ABBREVIATIONS

AiT	-	Avtomatika i telemekhanika
APP	-	Acta physica polonica
DAN ArmSSR	-	Akademiya nauk Armyanskoy SSR. Doklady
DAN AzSSR	-	Akademiya nauk Azerbaydzhanskoy SSR. Doklady
DAN BSSR	-	Akademiya nauk Belorusskoy SSR. Doklady
DAN SSSR	-	Akademiya nauk SSSR. Doklady
DAN TadSSR	-	Akademiya nauk Tadzhikskoy SSR. Doklady
DAN UkrSSR	-	Akademiya nauk Ukrayins'koyi RSR. Dopovidi
DAN UzbSSR	-	Akademiya nauk Uzbekskoy SSR. Doklady
DBAN	-	Bulgarska akademiya na naukite. Doklady
EOM	-	Elektronnaya obrabotka materialov
FAiO	-	Akademiya nauk SSSR. Izvestiya. Fizika atmosfery i okeana
FGiV	-	Fizika goreniya i vzryva
FiKhOM	-	Fizika i khimiya obrabotka materialov
F-KhMM	-	Fiziko-khimicheskaya mekhanika materialov
FMiM	-	Fizika metallov i metallovedeniye
FNT	-	Fizika nizkikh temperatur
FTP	-	Fizika i tekhnika poluprovodnikov
FTT	-	Fizika tverdogo tela
FZh	-	Fiziologicheskiy zhurnal
GiA	-	Geomagnetizm i aeronomiya
GiK	-	Geodeziya i kartografiya
IAN Arm	-	Akademiya nauk Armyanskoy SSR. Izvestiya. Fizika
IAN Az	-	Akademiya nauk Azerbaydzhanskoy SSR. Izvestiya. Seriya fiziko-tekhnicheskikh i matematicheskikh nauk

IAN B	-	Akademiya nauk Belorusskoy SSR. Izvestiya. Seriya fiziko-matematicheskikh nauk
IAN Biol	-	Akademiya nauk SSSR. Izvestiya. Seriya biologicheskaya
IAN Energ	-	Akademiya nauk SSSR. Izvestiya. Energetika i transport
IAN Est	-	Akademiya nauk Estonskoy SSR. Izvestiya. Fizika, matematika
IAN Fiz	-	Akademiya nauk SSSR. Izvestiya. Seriya fizicheskaya
IAN Fizika zemli	-	Akademiya nauk SSSR. Izvestiya. Fizika zemli
IAN Kh	-	Akademiya nauk SSSR. Izvestiya. Seriya khimicheskaya
IAN Lat	-	Akademiya nauk Latviyskoy SSR. Izvestiya
IAN Met	-	Akademiya nauk SSSR. Izvestiya. Metally
IAN Mold	-	Akademiya nauk Moldavskoy SSR. Izvestiya. Seriya fiziko-tekhnicheskikh i matematicheskikh nauk
IAN SO SSSR	-	Akademiya nauk SSSR. Sibirskoye otdeleniye. Izvestiya
IAN Tadzh	-	Akademiya nauk Tadzhikskoy SSR. Izvestiya. Otdeleniye fiziko-matematicheskikh i geologo-khimicheskikh nauk
IAN TK	-	Akademiya nauk SSSR. Izvestiya. Tekhnicheskaya kibernetika
IAN Turk	-	Akademiya nauk Turkmenskoy SSR. Izvestiya. Seriya fiziko-tekhnicheskikh, khimicheskikh, i geologicheskikh nauk
IAN Uzb	-	Akademiya nauk Uzbekskoy SSR. Izvestiya. Seriya fiziko-matematicheskikh nauk
IBAN	-	Bulgarska akademiya na naukite. Fizicheski institut. Izvestiya na fizicheskaya institut s ANEB
I-FZh	-	Inzhenerno-fizicheskiy zhurnal

IiR	-	Izobretatel' i ratsionalizator
ILEI	-	Leningradskíy elektrotekhnicheskiy institut. Izvestiya
IT	-	Izmeritel'naya tekhnika
IVUZ Avia	-	Izvestiya vysshikh uchebnykh zavedeniy. Aviatsionnaya tekhnika
IVUZ Cher	-	Izvestiya vysshikh uchebnykh zavedeniy. Chernaya metallurgiya
IVUZ Energ	-	Izvestiya vysshikh uchebnykh zavedeniy. Energetika
IVUZ Fiz	-	Izvestiya vysshikh uchebnykh zavedeniy. Fizika
IVUZ Geod	-	Izvestiya vysshikh uchebnykh zavedeniy. Geodeziya i aerofotos'yemka
IVUZ Geol	-	Izvestiya vysshikh uchebnykh zaveniy. Geologiya i razvedka
IVUZ Gorn	-	Izvestiya vysshikh uchębnykh zavedeniy. Gornyy zhurnal
IVUZ Mash	-	Izvestiya vysshikh uchebnykh zavedeniy. Mashinostroyeniye
IVUZ Priboro	-	Izvestiya vysshikh uchebnykh zavedeniy. Priborostroyeniye
IVUZ Radioelektr	-	Izvestiya vysshikh uchebnykh zavedeniy. Radioelektronika
IVUZ Radiofiz	-	Izvestiya vysshikh uchebnykh zavedeniy. Radiofizika
IVUZ Stroi	-	Izvestiya vysshikh uchebnykh zavedeniy. Stroitel'stvo i arkhitektura
KhVE	-	Khimiya vysokikh energiy
KiK	-	Kinetika i kataliz
KL	-	Knizhnaya letopis'
Kristall	-	Kristallografiya
KSpF	-	Kratkiye soobshcheniya po fizike

LZhS	-	Letopis' zhurnal'nykh statey
MiTOM	-	Metallovedeniye i termicheskaya obrabotka materialov
MP	-	Mekhanika polimerov
MTT	-	Akademiya nauk SSSR. Izvestiya. Mekhanika tverdogo tela
MZhiG	-	Akademiya nauk SSSR. Izvestiya. Mekhanika zhidkosti i gaza
NK	-	Novyye knigi
NM	-	Akademiya nauk SSSR. Izvestiya. Neorganicheskiye materialy
NTO SSSR	-	Nauchno-tekhnicheskiye obshchestva SSSR
OiS	-	Optika i spektroskopiya
OMP	-	Optiko-mekhanicheskaya promyshlennost'
Otkr izobr	-	Otkrytiya, izobreteniya, promyshlennyye obraztsy, tovarnyye znaki
PF	-	Postepy fizyki
Phys abs	-	Physics abstracts
PM	-	Prikladnaya mekhanika
PMM	-	Prikladnaya matematika i mekhanika
PSS	-	Physica status solidi
PSU	-	Pribory i sistemy upravleniya
PTE	-	Pribory i tekhnika eksperimenta
Radiotekh	-	Radiotekhnika
RiE	-	Radiotekhnika i elektronika
RZhAvtom	-	Referativnyy zhurnal. Avtomatika, telemekhanika i vychislitel'naya tekhnika
RZhElektr	-	Referativnyy zhurnal. Elektronika i yeye primeneniye

RZhF	-	Referativnyy zhurnal. Fizika
RZhFoto	-	Referativnyy zhurnal, Fotokinotekhnika
RZhGeod	-	Referativnyy zhurnal. Geodeziya i aeros"-yemka
RZhGeofiz	-	Referativnyy zhurnal. Geofizika
RZhInf	-	Referativnyy zhurnal. Informatics
RZhKh	-	Referativnyy zhurnal. Khimiya
RZhMekh	-	Referativnyy zhurnal. Mekhanika
RZhMetal	-	Referativnyy zhurnal. Metallurgiya
RZhMetrolog	-	Referativnyy zhurnal. Metrologiya i izmeritel'naya tekhnika
RZhRadiot	-	Referativnyy zhurnal. Radiotekhnika
SovSciRev	-	Soviet science review
TiEKh	-	Teoreticheskaya i eksperimental'naya khimiya
TKiT	-	Tekhnika kino i televideniya
TMF	-	Teoreticheskaya i matematicheskaya fizika
TVT	-	Teplofizika vysokikh temperatur
UFN	-	Uspekhi fizicheskikh nauk
UFZh	-	Ukrainskiy fizicheskiy zhurnal
UMS	-	Ustalost' metallov i splavov
UNF	-	Uspekhi nauchnoy fotografii
VAN	-	Akademiya nauk SSSR. Vestnik
VAN BSSR	-	Akademiya nauk Belorusskoy SSR. Vestnik
VAN KazSSR	-	Akademiya nauk Kazakhskoy SSR. Vestnik
VBU	-	Belorusskiy universitet. Vestnik
VNDKh SSSR	-	VNDKh SSSR. Informatsionnyy byulleten'
VLU	-	Leningradskiy universitet. Vestnik. Fizika, khimiya
VMU	-	Moskovskiy universitet. Vestnik. Seriya fizika, astonomiya

ZhETF	–	Zhurnal eksperimental'noy i teoreticheskoy fiziki
ZhETF P	–	Pis'ma v Zhurnal eksperimental'noy i teoreticheskoy fiziki
ZhFKh	–	Zhurnal fizicheskoy khimii
ZhNiPFiK	–	Zhurnal nauchnoy i prikladnoy fotografii i kinematografii
ZhNKh	–	Zhurnal neorganicheskoy khimii
ZhPK	–	Zhurnal prikladnoy khimii
ZhPMTF	–	Zhurnal prikladnoy mekhaniki i tekhnicheskoy fiziki
ZhPS	–	Zhurnal prikladnoy spektroskopii
ZhTF	–	Zhurnal tekhnicheskoy fiziki
ZhTFP	–	Pis'ma v Zhurnal tekhnicheskoy fiziki.
ZhVMMF	–	Zhurnal vychislitel'noy matematiki i matematicheskoy fiziki
ZL	–	Zavodskaya laboratoriya

7. AUTHOR INDEX

N

Nguen Min'Khiyen   58
Nguyen Tkho Vyong   3

O

Obukhov, L. A.   55
Ol'skaya, M. A.   45

P

Plyatsko, G. V.   27

R

Rudnev, A. N.   23
Rykalin, N. N.   14

S

Samarin, A. V.   71
Samsonov, G. V.   12
Shkedov, I. M.   99
Smirnov, V. N.   72
Stavrov, A. A.   113

T

Tananykhin, A. A.   19
Tovstyuk, K. D.   59, 60
Tribel'skiy, M. I.   53

U

Uglov, A. A.   85, 86

V

Vlasov, D. V.   47
Volkov, S. A.   78

Y

Yanushkevich, V. A.   80
Yepifanov, A. S.   49
Yeron'ko, S. B.   32

Z

Zakharenkov, Yu. A.   108
Zapechel'nyuk, E. F.   37
Zemlyanov, A. A.   80
Zhiryakov, B. M.   8